DAMPING CAPACITY
TESTING MACHINE

BY
SCHUYLER WILSHEAR BACON

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S. W. Bacon

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PREFACE

While much work has been done to determine the damping capacity of metals during the past twenty years, only a small portion of these investigations has obtained damping information at elevated temperatures. Accordingly, it was decided to construct a machine for finding the damping capacity of metals between room temperature and 500 degrees F. and to test its accuracy using a metal sample whose damping capacity has been previously established.

During the period from April, 1949 to April, 1950, work was done by the author on the damping machine and a suitable amplitude measuring device at the United States Naval Postgraduate School, Annapolis, Maryland.

The author gratefully acknowledges the assistance of Dr. Ernest K. Gatcombe during the project. Acknowledgements are also due to Professor W. Colney Smith, Postgraduate School, for his assistance in the design of the amplitude measuring system; to The U. S. Naval Engineering Experiment Station and Mr. J. A. Oktavec of the Postgraduate School for the construction of the mechanical portion of the machine; to Mr. Robert Plate, Engineering Experiment Station, for providing the insulating materials; to Mr. George Gary, Engineering Experiment Station, for his photographic services; to Mr. Richard C. Bartlett, Engineering Experiment Station, for extending to the author the use of the thermocouple calibration facilities; to the Public

Works Department, U. S. Naval Academy for making the drawings; and to members of the departments of Mechanical Engineering, Electrical Engineering, and Electronics Engineering for providing much of the associated equipment and instruments used on the project.

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LIST OF ILLUSTRATIONS

TABLE OF SYMBOLS

AND ABBREVIATIONS

A, A_1	Constants
a	Number of cycles
b	Mean grain size of sample
D	Specific damping capacity
e	Total vibrational energy in sample, inch pounds
Δe	Energy of vibration dissipated per cycle, inch pounds
E	Modulus of elasticity. Pounds per square inch.
f	Frequency of vibration, cycles per second.
g	Acceleration due to gravity, inches per second square
h	Distance from neutral axis of cantilever to extreme fiber, inches.
I	Moment of inertia, inches^4
l	Length of cantilever, inches.
P	Potential energy of cantilever, inch pounds.
t	Time, seconds
w	Weight of cantilever per unit length. Pounds (force) per inch.
x	Axial distance from fixed end of cantilever, Inches.
y	Amplitude of vibration, inches
y_1	Amplitude at end of cantilever, Inches.
y_n	Amplitude of n^{th} cycle, inches

TABLE OF SYMBOLS

AND ABBREVIATIONS (CONT.)

$y_{(n+a)}$	Amplitude of $(n+a)^{th}$ cycle, inches.
δ	Logarithmic decriment
σ_1	Maximum stress in extreme fiber at X-0, pounds per square inch.
ω	Angular velocity, Radians per second.

I

INTRODUCTION

1. Significance of damping capacity.

Damping capacity of a material is a property which causes vibrational energy to be dissipated even when energy losses to such surrounding systems as the air or supporting structures are zero. The engineer is interested in damping capacity or internal friction for several reasons. It may be used as an indication of metallurgical structural variations within metals and has been correlated with such properties as creep and plastic deformation. Damping capacity of a material will be greater than normal if internal defects are present and nondestructive testing may thereby be made. Damping affects the nature of vibrations in materials. Systems undergoing free vibrations caused by shock will cease vibrating at a time that is a function of the internal friction. Systems vibrating under the stimulus of a periodic force are limited in amplitude at resonance by the damping capacity. Thus turbine blades with high damping capacity are desired to limit the maximum stress caused by blade vibration at resonant speeds.

Damping capacity is considered when it is desired to reduce the noise of rotating machinery, as illustrated by the increasing use of plastic gears. Also where temperature rise, caused by the dissipation of vibrational energy, affects the properties of materials, notably plastics, their damping must be considered.

2. Objective of thesis.

One important variable causing a change in the internal friction of a given metal is its temperature. A survey of the literature has shown that the variation of damping capacity with temperature has been investigated only to a limited degree and has not keptup with the increasing temperatures utilized in machinery today.

Accordingly, the object of this thesis is to design, construct, and test the accuracy of a machine for the determination of the damping capacity of metals at elevated temperatures.

3. Summary

The damping machine as designed and constructed, figure 46, provides a means of vibrating a heated cantilever metal sample in free vibration and recording its amplitude during decay. The damping capacity, expressed as the unit specific damping capacity, was determined from the logarithmic decriment. Damping capacity tests were made at various temperatures from 78 degrees F. to 699 degrees F. on a sample of S.A.E. 1020 steel. Tests indicated a slight increase of damping capacity with stress over the maximum fiber stress range of 1,000-6,000 psi. The specific damping capacity reached a maximum value of about 0.020 for a cantilever free end temperature of 278 degrees F. For 78 degrees F. and 699 degrees F., the specific damping capacity is 0.010-0.012.

II

DESIGN

1. Considerations

The magnitude of the internal friction within a given metal depends on several variables that must be controlled during an investigation. These variables are discussed in the appendix. Grain size, condition of anneal, and whether or not the sample is ferromagnetic are of course decided by selection of the sample. However, control of the other variables; stress amplitude, frequency of oscillation, and temperature had to be provided in the design.

At the outset it was considered necessary to select a test procedure that controlled these variables and incorporated the following features in testing for damping capacity:

a. Provision for a range of stress amplitude up to the proportional limit with reasonable amplitudes of motion.

b. Variation of temperature from room temperature to 500°F.

c. Provision for oscillation at constant frequency with a method of changing the frequency employed.

d. Elimination of the damping due to air friction and support losses.

e. Provision for accurate measurement of the damping capacity without introducing external damping into the system.

f. Provision for accurate temperature measurement of the sample without introducing external damping.

g. Low cost.

So as to best devise a method of testing that would meet these conditions, much of the work in the field of damping measurements was reviewed. There are several methods that have been extensively employed. While it was considered that none of these procedures in their entirety would be suitable to meet the aims of this investigation, it was apparent that the often used method of determining damping capacity from the amplitude decriment of free vibration would be the most suitable method of approach. The forced vibration method caused by magnetic excitation, Zener (15), or pizoelectric excitation as used by Cabarat (1), while accurate as regards suspension losses and amplitude measurement, was rejected because it provides no suitable means for appreciable stress amplitude. The possibility of using this method with the available Westinghouse vibration fatigue testing equipment was considered. Suitable stress could be induced thereby but the damping introduced by the supporting springs would give rise to correction of the results. The torsional vibration method as used in the Foppe-Pertz type of machine, Cottell (3), Hatfield (5), is popular and the machine is available commercially. However, no reliable method of amplitude measurement, under the conditions imposed, presented itself. For the same reason, modifications of this method using a mechanical oscillator, Lazan (8), Robertson (10), were not considered. Another method of determining internal friction consists of measuring the area under the stress-strain hysteresis loop, von Heydekampf (14), Rowett (11). This test

procedure gives poor results at low stresses, especially for low damping capacity metals. There are two methods of finding the energy dissipated per cycle by very accurately knowing the temperature of the sample during oscillation or immediately thereafter, von Heydekampf (14). Again the conditions imposed; elevated temperature inside a vacuum without the introduction of external damping by temperature measuring instruments, precluded the use of such a method. The method used by Kimball, (7), utilizing shaft whirl allows no possibility of determining the frequency effect on damping. Another possibility; the measurement of the energy input causing vibration at constant amplitude, is not as accurate as the previous methods.

2. Test method.

The method used for finding the damping capacity employed a rectangular cantilever sample in free vibration; damping being expressed as the unit, specific damping capacity, which is the ratio of the vibrational energy dissipated per cycle to the total vibrational energy in the sample. In the appendix it is shown that specific damping capacity, D, equals twice the logarithmic decriment, δ, for free vibration where:

$$\delta = \frac{1}{a} \ln\left(\frac{y_n}{y_{n+a}}\right) \qquad (1).$$

Amplitudes during the decaying vibration were determined experimentally and the decriment was found from equation (1) at various maximum stresses and temperatures for one frequency. The specific damping capacity was obtained from the decriment. The number of intervening cycles, a, between the amplitudes used in equation (1) was arbitrarily chosen to be 10, 15, or 20. Fewer cycles would

result in less accuracy since the amplitude difference would be small. More intervening cycles would result in a greater maximum stress range for which the decriment was determined.

3. Testing Machine.

To accomplish the free vibration and amplitude measurement of the heated cantilever sample, the machine shown in figures 1,2,3 and 46 was constructed. It consists of a circular base, two attached blocks holding the rectangular sample as a cantilever in a vertical position, a mechanism to displace the sample in a curve closely approximating its fundamental mode with provision for sudden release, a condenser with support bracket for amplitude measurement, an electric, Nichrome wound, insulated, muffle furnace surrounding the sample and condenser, and a bell jar with protective water jacket. The system is evacuated through the base; the air being cooled by a heat exchanger before entering the vacuum pump. Initial displacement of the sample is effected by an arm contacting the cantilever at its free end and release is accomplished by a magnetic solenoid attached to a spring loaded trigger mechanism. Calibrated iron-constantan thermocouples were employed for temperature measurement of the sample fixed end, figure 4 and the free end, figure 5. Temperature of the fixed end of the sample was obtained at a point 1/8 inch below the top surface of the support blocks by inserting the thermocouple in a semicircular drilled hole adjacent to the

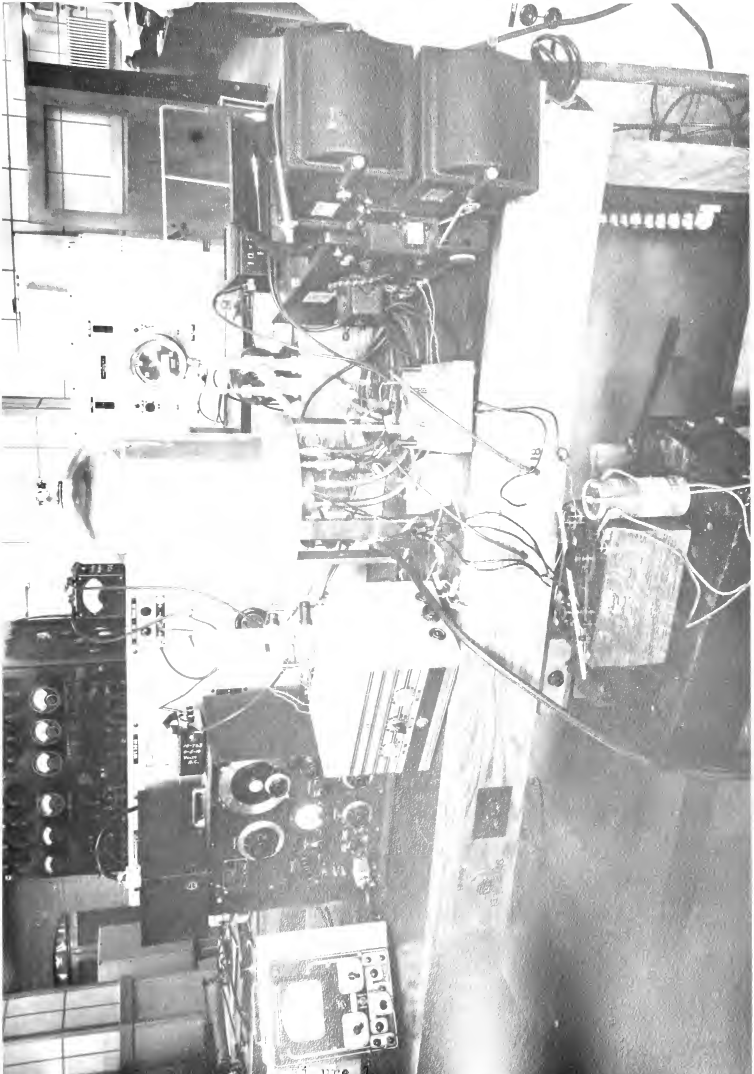
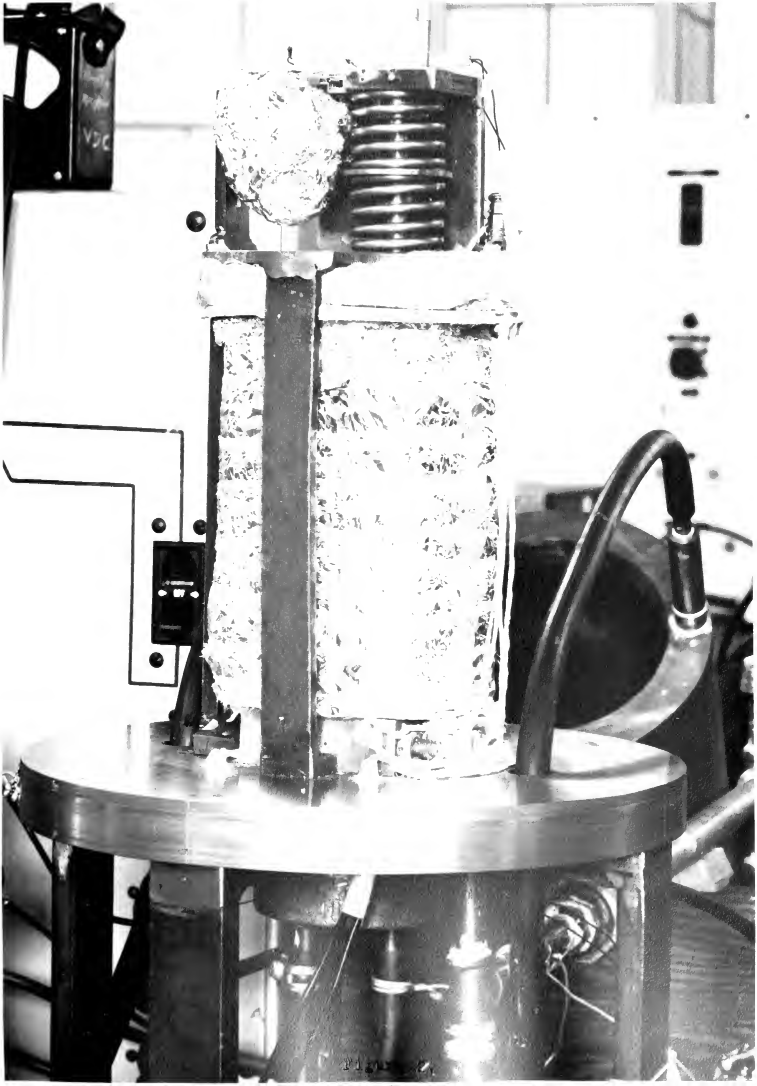


Figure 1.



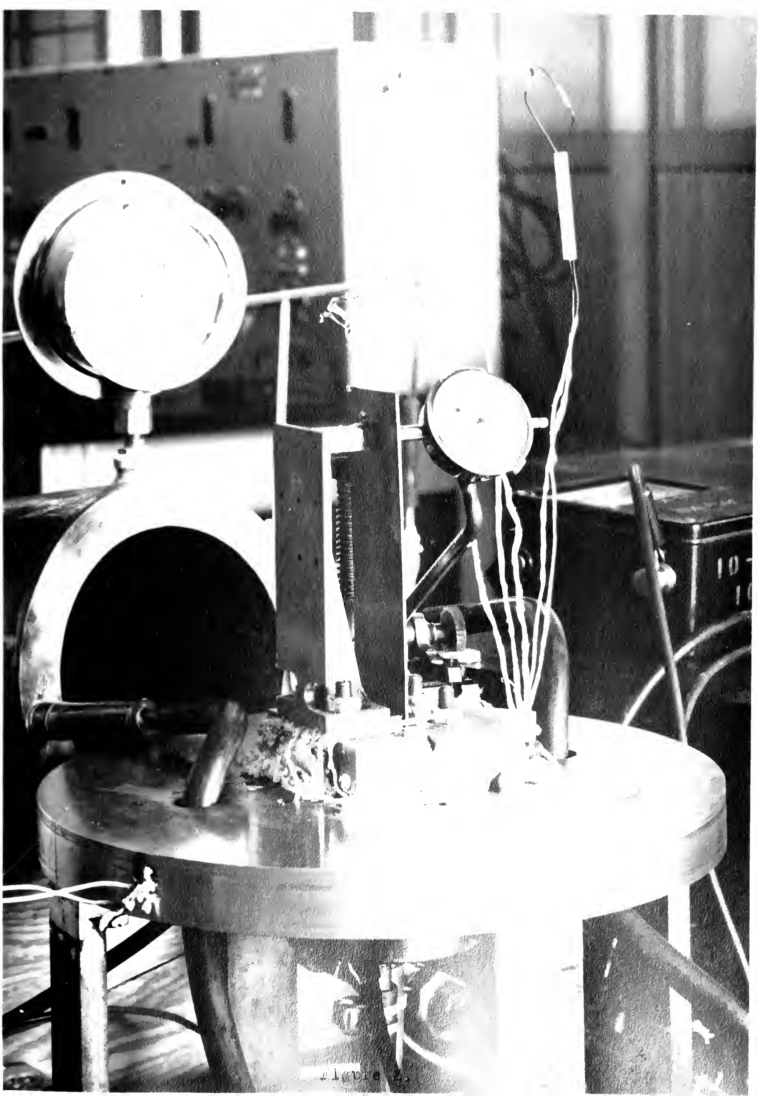
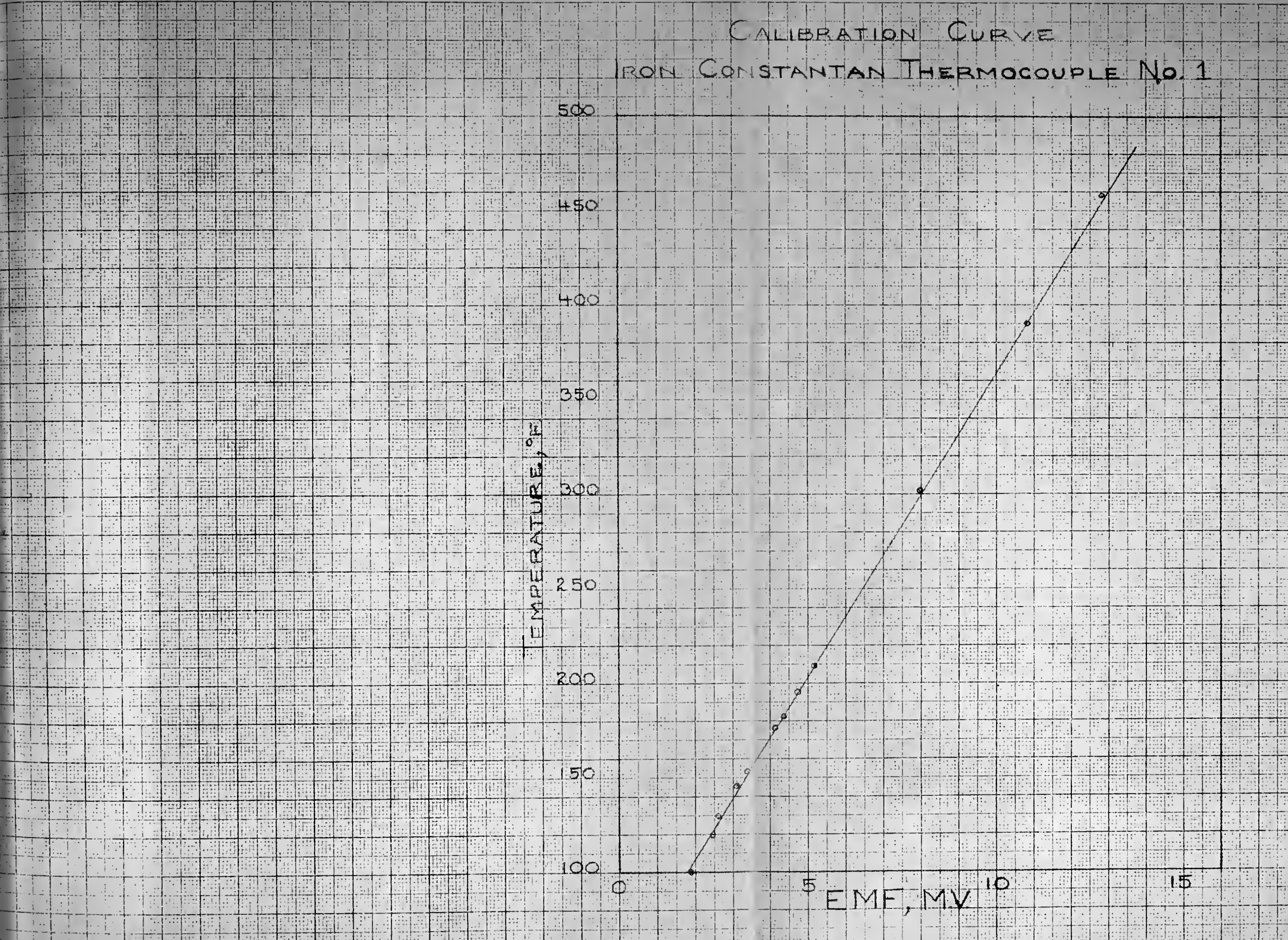
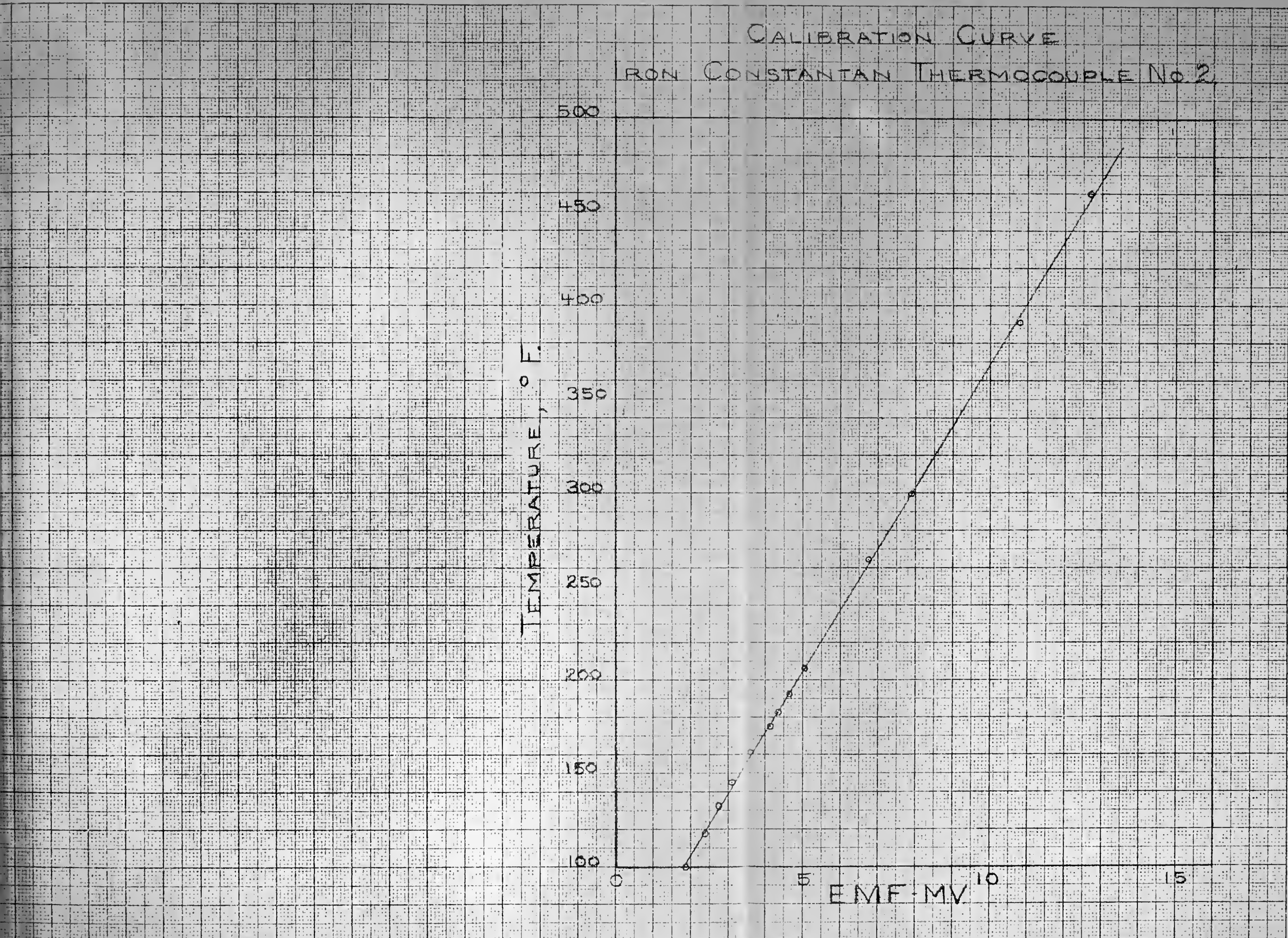


Figure 4.



CALIBRATION CURVE
IRON CONSTANTAN THERMOCOUPLE No. 1
TEMPERATURE, °F
500
450
400
350
300
250
200
150
100
0
5
10
15
EMF, MV



CALIBRATION CURVE
IRON CONSTANTAN THERMOCOUPLE No. 2
TEMPERATURE, °F.
500
450
400
350
300
250
200
150
100
0
5
10
15
EMF MV

sample. The temperature of the free end was obtained by placing the thermocouple in a hole in the release arm in such a manner that it touched the sample before release. For simplicity of design the thermocouple, furnace, and condenser leads entered the system through drilled holes in the base, which were vacuum sealed by high temperature resistant, alumina oxide-sodium silicate cement. Insulation of these leads adjacent to the furnace and base was accomplished by coating with this cement or covering with standard alumina oxide thermocouple tubes.

Specifications of the testing machine are as follows:

Maximum sample size, 5.88" x 2" x 1/2"

Size of sample used, 5.88" x 2" x 0.05"

Maximum fiber stress of 5.88" x 0.05" sample, 92,600 psi per inch of free end dynamic deflection.

Natural frequency of 5.88" x 0.05" sample,
Room temperature, 48.0 cycles per second
699 degrees F., 46.4 cycles per second

Frequency variation may be provided by shortening sample or by attaching mass to end of sample. (Not used during tests.)

Furnace

Maximum capacity, 1.0 K.W.
Winding, 30 feet, Nichrome, 14 A.W.G.
Maximum temperature of insulation, 1000° F.
Muffle size, 2 1/2" x 3 3/16" x 7" inside

Insulation: 1/2 to 3/4 inch glass wool and aluminum foil on sides.
3/4 inch asbestos mill board, aluminum foil and glass wool on top.

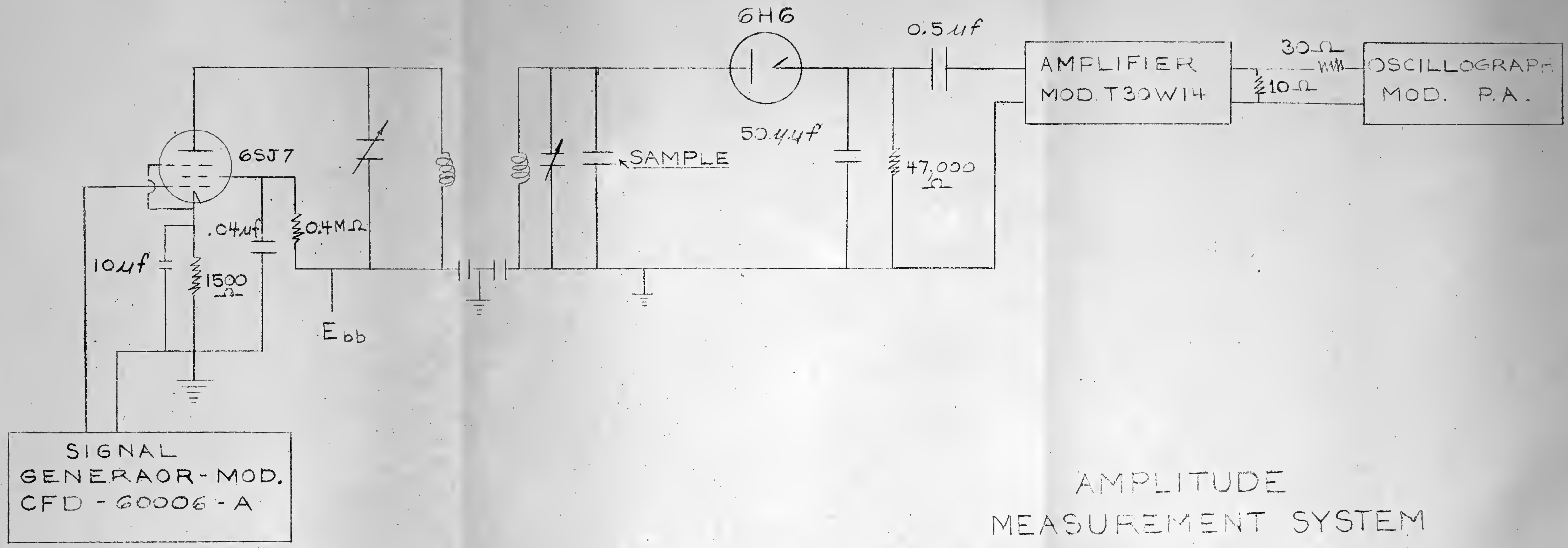
Maximum recommended furnace temperature to avoid burning release solonoid insulation, 700 degress F.

III

AMPLITUDE MEASUREMENT

1. Pickup and associated equipment.

An electrical pickup was designed and constructed to reproduce the amplitude of vibration without the introduction of damping. The arrangement is shown in figure 6. The vibrating sample was employed as a condenser plate in conjunction with a 1/2 inch diameter plate secured at a fixed distance from the neutral axis. Thus the capacitance herein varied almost linearly for small amplitudes of motion. This capacitance, together with a tunable condenser and a fixed inductance formed the secondary of a tuned primary-secondary output of a 6SJ7 pentode. The pentode was fed by a signal generator; the amplified wave being rectified in the secondary circuit by a 6H6 diode. Thus the carrier wave in the secondary was modulated by the change in pickup capacitance due to the amplitude of motion. Demodulation in the diode and resistance capacitance load resulted in pulsating current, the alternating component of which was amplified by a Thordarsen audio amplifier. This amplifier contained a power stage which supplied the necessary current to record the wave in a Westinghouse, Type PA oscillograph. The power stage of the amplifier fed a matched parallel resistance load; one branch being in series with the oscillograph element and having the proper resistance to give an acceptable recorded wave size.



AMPLITUDE
MEASUREMENT SYSTEM

2. Amplitude determination

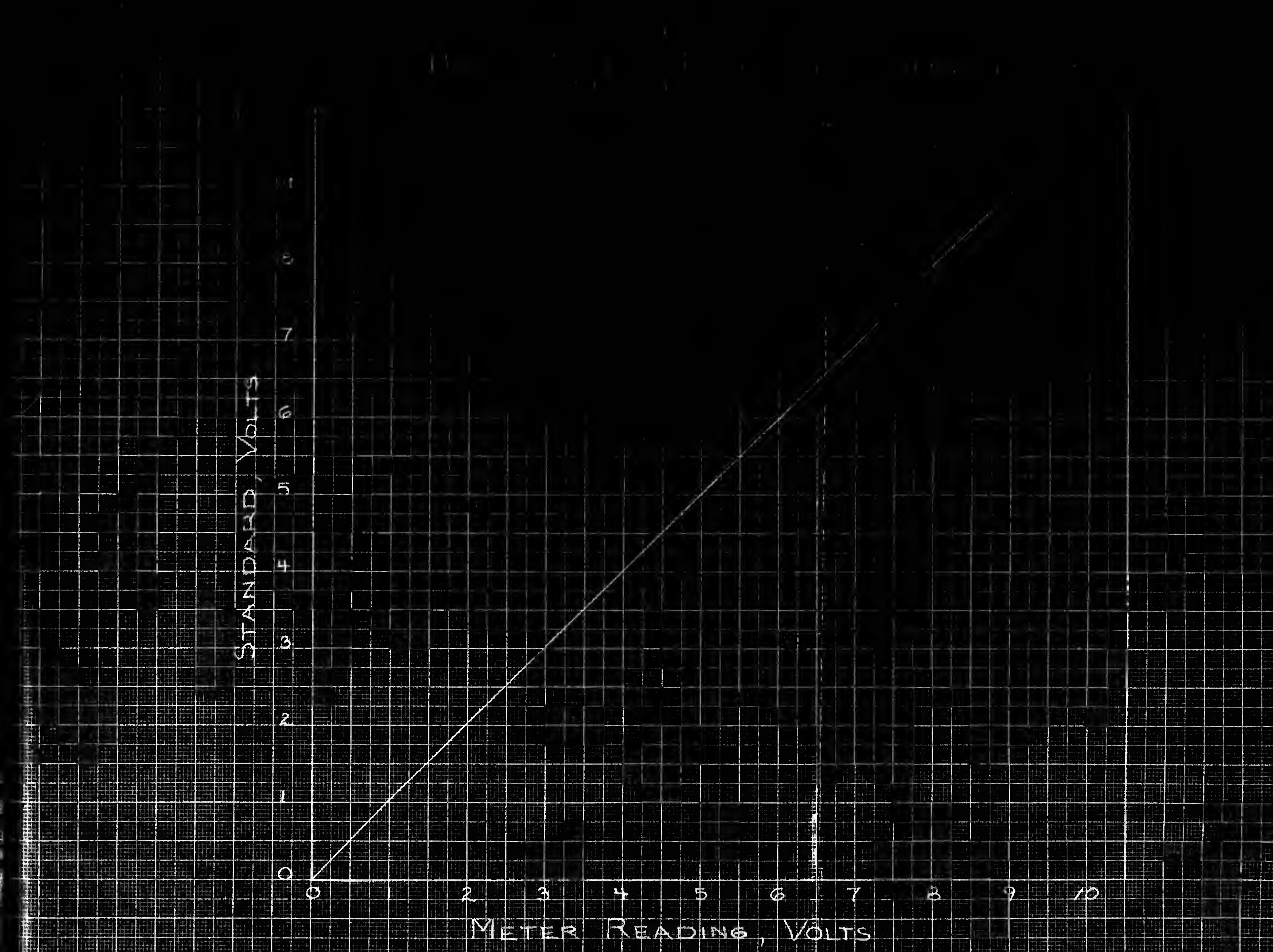
To find the amplitude of vibration at any cycle from the trace produced by the oscillograph, it was necessary to perform the following calculations:

a. Find voltage input to oscillograph. Since the trace had a scale factor of 150 m.a. per inch of deflection and a resistance of 30.8 ohms was in series with this circuit, the instantaneous voltage output from the amplifier to the oscillograph was 4.62 volts per inch of deflection.

b. Find voltage input to amplifier. This was accomplished by calibrating the amplifier for each run and obtaining a curve of instantaneous voltage output vs. instantaneous voltage input at the same amplifier gain as used during the test. Oscillator frequency equal to that of the sample, 48 cycles per second, was used.

c. Determine amplitude of motion. Prior to each test a displacement of sample vs. voltage across diode output curve was obtained using a dial gage, figure 3. The calibration curve of the voltmeter is shown in figure 7. By shifting the voltage axis to a point corresponding to the diode voltage at zero displacement and entering the curve for the value of amplifier input, the corresponding sample amplitude was determined.

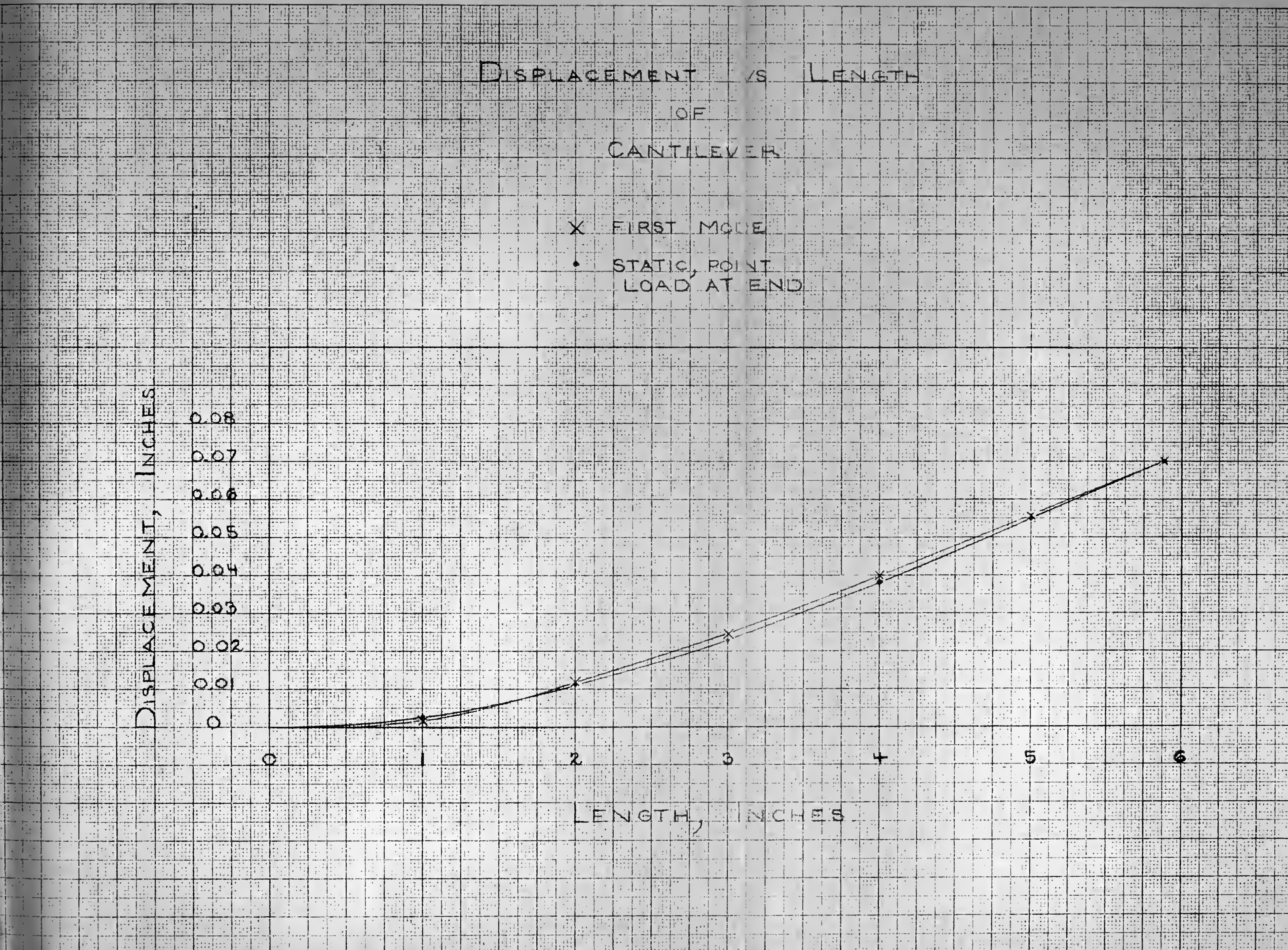
It is to be noted that the amplitude axis of the oscillograph curve as recorded is about the average value of the diode voltage.


Standard, Volts
Meter Reading, Volts
0
1
2
3
4
5
6
7
8
9
10

Accordingly, amplitude values on the oscillograph curve were scaled from an axis for which the displacement of the sample was zero. This was readily found as the axis where the time for both halves of a full cycle was equal. Test results showed that modes of vibration other than the first were present owing to the fact that the static displacement did not quite correspond to the dynamic displacement of the first mode. A comparison of this difference for one value of free end displacement is illustrated in figure 8. Vibration during decay was not periodic. However, the variation from periodic motion was found to be very small and the assumption that the time for each half cycle was equal was used.

For some runs, the oscillator frequency and the capacitance in parallel with the sample were tuned so that the diode voltage reached a maximum at a value of sample amplitude that was less than the initial amplitude. For such amplitudes of motion, the oscillograph trace shows double maximum in a half cycle; these double peaks remaining until the amplitude of motion is equal to or less than the value for which it was originally tuned to give maximum diode voltage.

To position the dial gage for the displacement vs. diode voltage characteristics of each test, it was necessary to remove the water jacket, release mechanism base, and furnace, figure 3. Subsequent assembly of these parts results in increased capacitance to ground. With the sample in the undisplaced position, the value



DISPLACEMENT VS LENGTH
OF
CANTILEVER
X FIRST MODE
• STATIC, POINT LOAD AT END
DISPLACEMENT, INCHES
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
1
2
3
4
5
6
LENGTH, INCHES

of diode voltage was then made equal to the value obtained during the dial gage run using the adjustable condenser in the secondary of the tuned circuit.

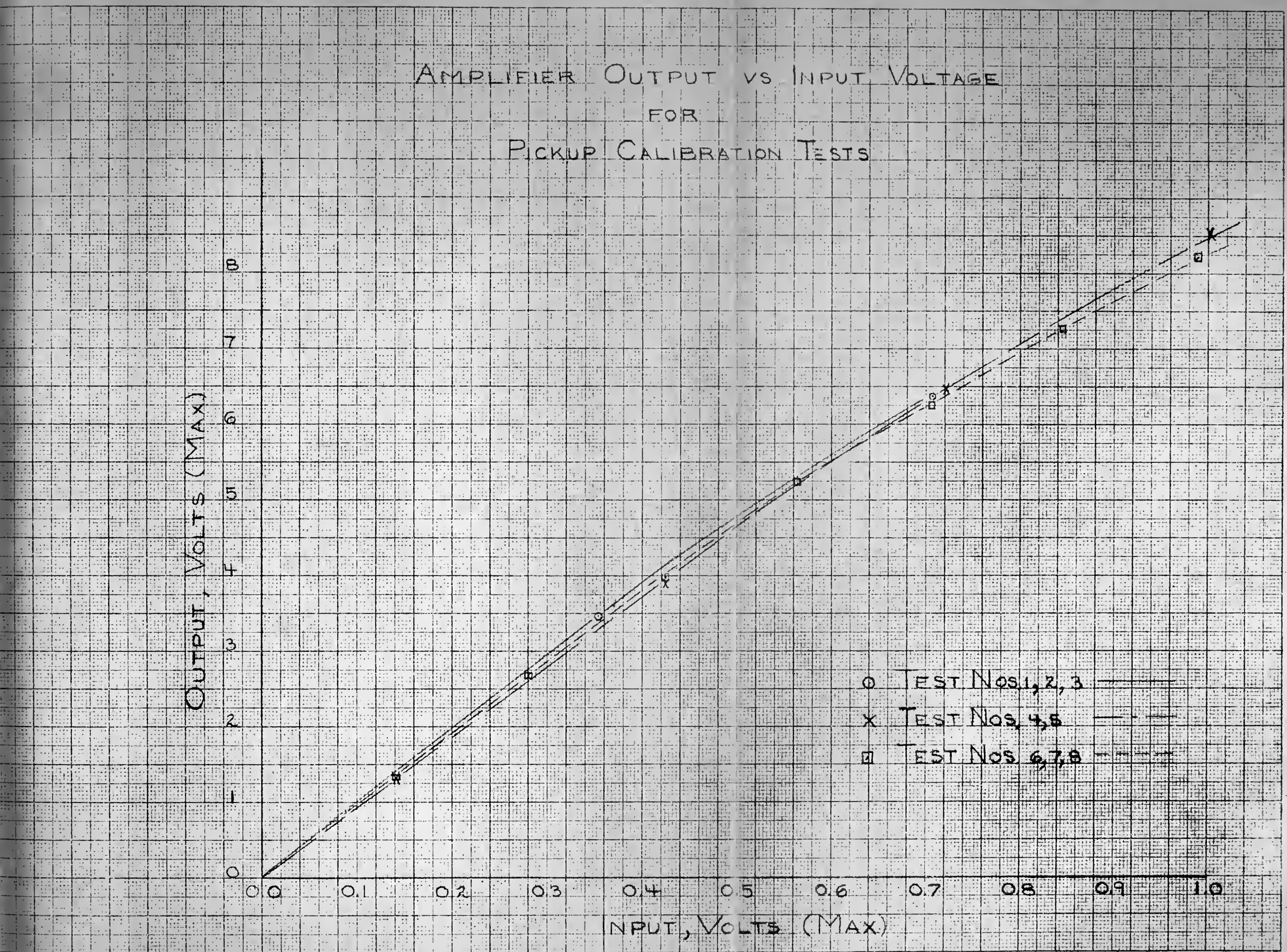
IV

CALIBRATION

1. Method

The amplitude measuring system was calibrated by making a series of runs with the maximum value of diode voltage tuned so as to occur at values of sample displacement ranging from 0.0145 to 0.0293 inches. Each run was made at initial amplitude of motion that was greater than that corresponding to the maximum diode voltage. From the maximum value of diode voltage for a given run and its value at zero displacement, the value of the voltage input to the amplifier was obtained. Using the amplifier gain and the oscillograph scale factor, the value of amplitude on the trace was calculated and checked against the actual height of the trace at the half cycle where the double peak changed to a single peak. Figure 9 gives the amplifier output-input voltage relations for these tests. Data and results are shown in figure 10 and the oscillographs are illustrated in figures 11-18. These calibration runs were made at room temperature and at atmospheric pressure since the values are valid for any value of damping.

In each case, the predicted height of the trace was equal to the calculated height within the accuracy of scaling the trace. Accordingly no calibration curve was needed.



AMPLIFIER OUTPUT VS INPUT VOLTAGE
FOR
PICKUP CALIBRATION TESTS
OUTPUT, VOLTS (MAX)
0
1
2
3
4
5
6
7
8
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
INPUT, VOLTS (MAX)
TEST NOS 1, 2, 3
TEST NOS 4, 5
TEST NOS 6, 7, 8

Figure 10

DATA AND RESULTS, PICKUP CALIBRATION

Test No.	Dial Gage Zero Sample Displacement	Readings Sample Displacement at Maximum Voltage Across Diode	Corrected D.C. Voltage Across Diode Output	Voltage Difference	Amplifier Output	Calculated ht. of Oscillograph Curve	Actual ht. of Oscillograph curve	Discrepancy
	Inches	Inches	Volts	Volts	Volts	Inches	Inches	Inches
1	o.2812	0.2635	5.57 6.04	0.47	4.52	0.977	0.98	+0.003
2	0.2810	0.2620	5.46 5.83	0.37	3.61	0.782	0.78	-0.002
3	0.2810	0.2620	5.46 5.83	0.37	3.61	0.782	0.77	-0.012
4	0.2787	0.2520	6.34 7.00	0.66	6.00	1.300	1.30	0.00
5	0.2768	0.2580	5.51 5.62	0.11	1.02	0.221	0.24	+0.019
6.	0.2660	0.2475	5.99 6.17	0.18	1.70	0.368	0.38	+0.012
7	0.1170	0.1025	6.95 7.05	0.10	0.94	0.203	0.20	+0.003
8	0.2300	0.2007	6.38 6.90	0.52	4.87	1.052	1.05	-0.002

Fig re 11

[illegible]

Figure 12

fg 12

Figure 13

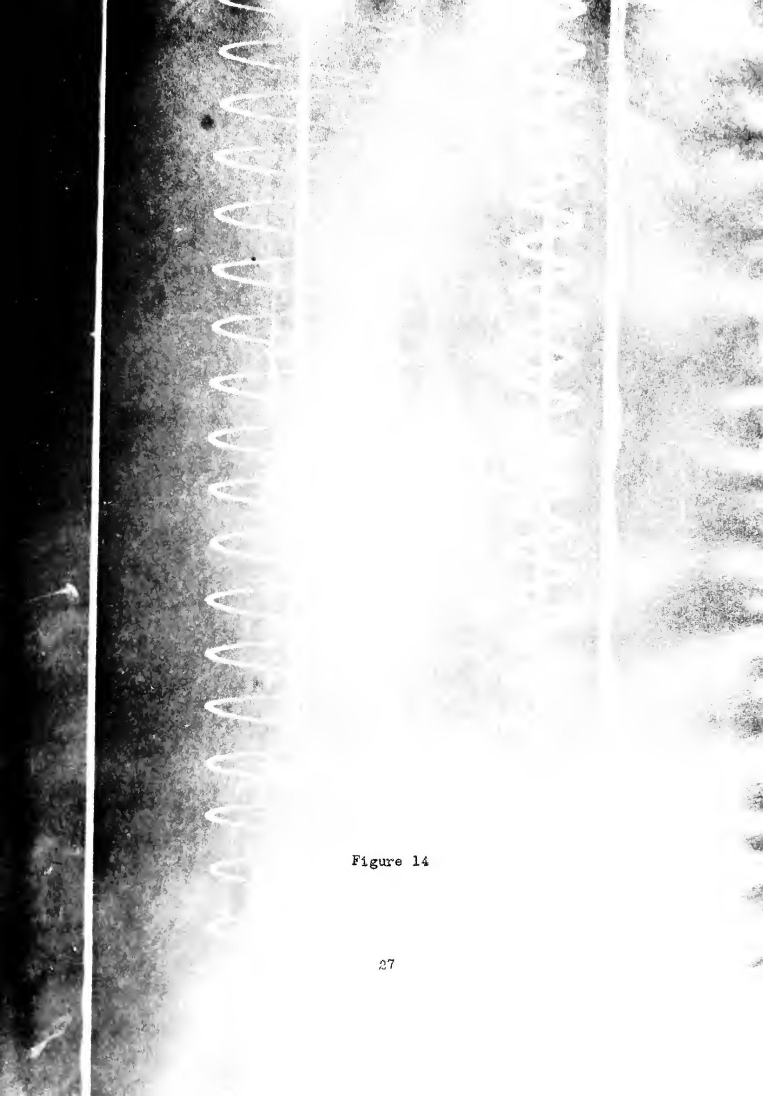


Figure 14

[illegible]

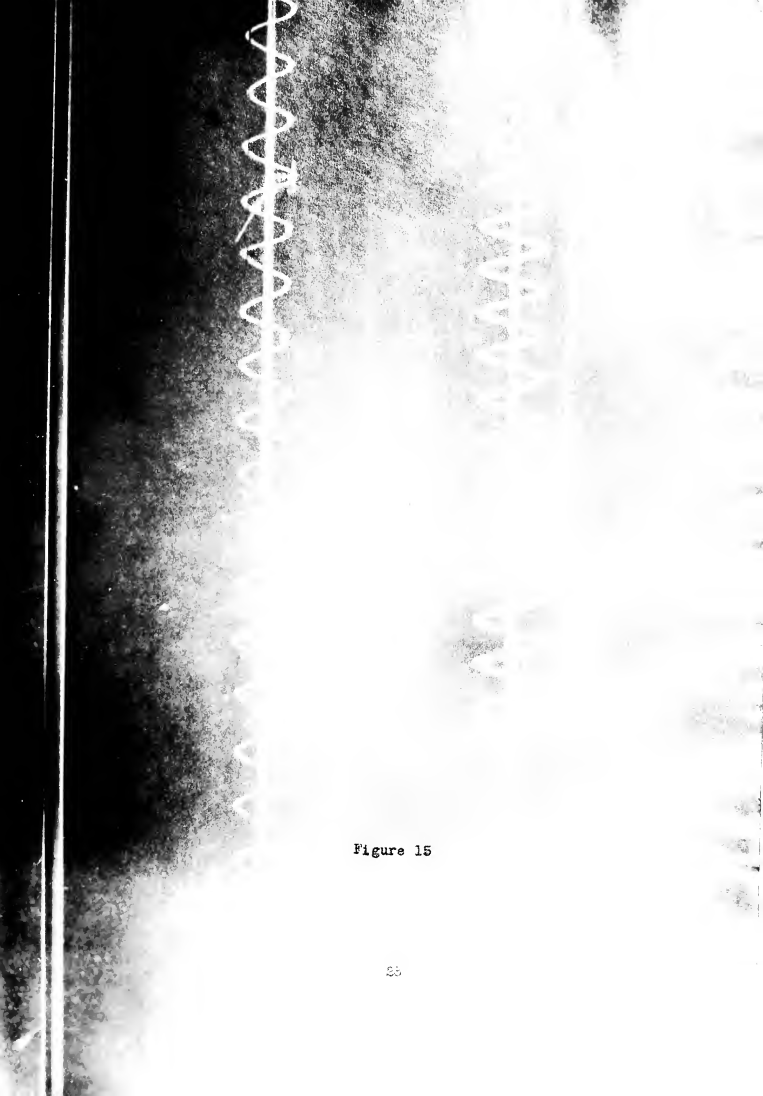


Figure 15

Figure 16

Fig 16

Figure 17

[illegible]

Figure 1.

V

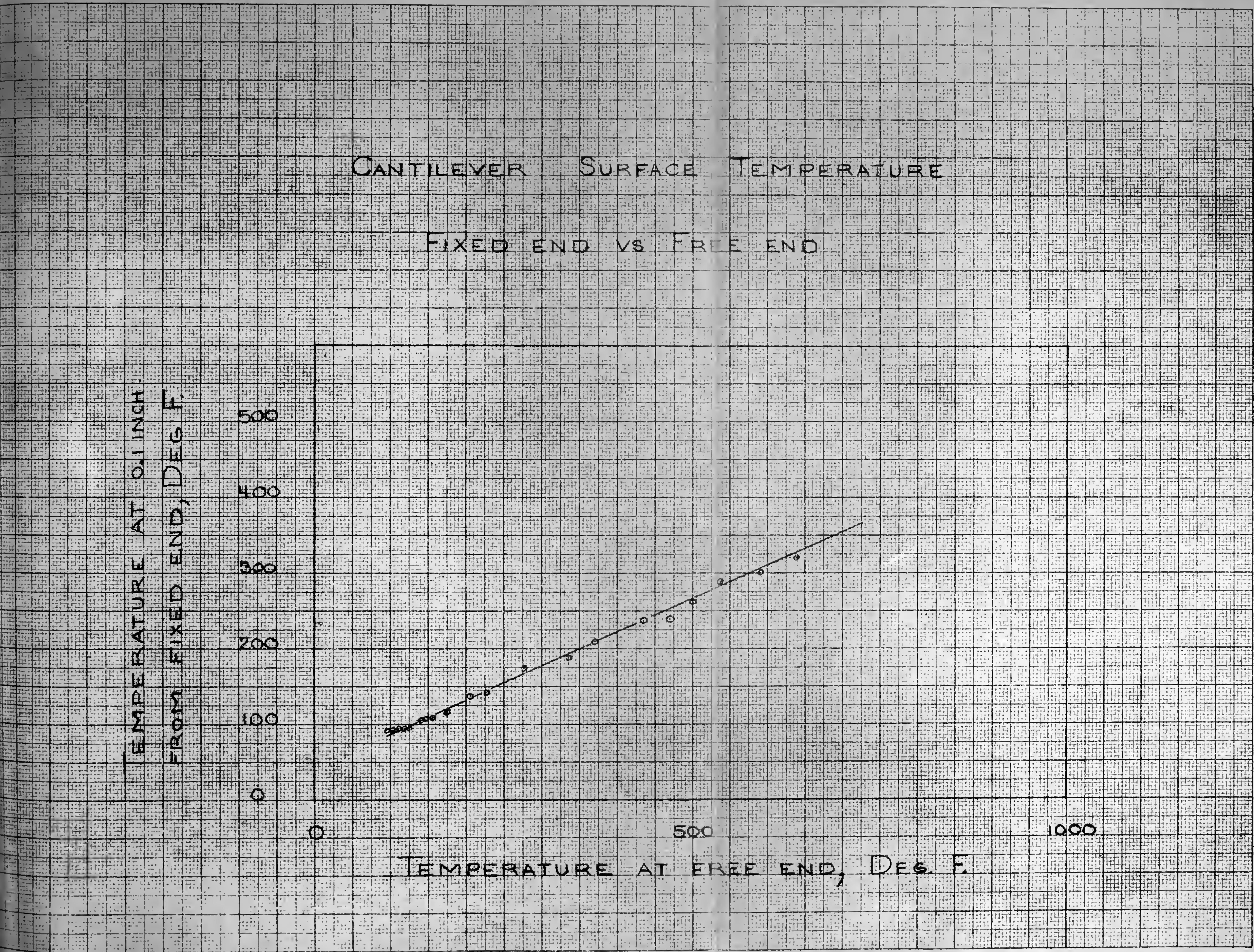
DAMPING TESTS

1. Procedure

The specific damping capacity of a sample of SAE 1020 steel was made at room temperature and at 4 elevated temperatures to 699 degrees F. To avoid any magnetization of the sample due to residual flux density, the alternating current to the furnace was gradually decreased to zero prior to each high temperature test. Temperature measurements at the base of the sample using the thermocouple inserted in the support block showed that considerable cooling resulted from the base and blocks. Therefore, a temperature comparison test was made between the free end and a point on the surface of the sample 0.1 inch above the fixed end, using a thermocouple temporarily secured at this point. Results of this test, shown in figure 19, indicate a sample surface temperature at 0.1 inch above the fixed end that equals 41 + 0.445 x temperature of the free end.

Since the thermocouple could not be clamped to the sample during the damping tests, the results were reported for the surface temperature of the free end and the estimated surface temperature 0.1 inch from the fixed end, as obtained from figure 19.

The amplitude measuring circuit as constructed is considered to be most accurate for a cantilever movement range of o.o35 inch.



CANTILEVER SURFACE TEMPERATURE
FIXED END VS FREE END
TEMPERATURE AT 0.1 INCH FROM FIXED END, DEG. F.
0
100
200
300
400
500
0
500
1000
TEMPERATURE AT FREE END, DEG. F.

The condenser plate was attached at a point 5.00 inches above the fixed end of the sample and for the sample size used, 0.05" x 5.88", the maximum fiber stress range corresponding to 0.035 inch amplitude difference is 3,240 psi. During the damping tests, amplitudes were selected to give maximum stresses from 5,500 psi to 2,000 psi for one room temperature test and the four high temperature tests. One run was made with amplitudes and tuning selected to give a lower maximum stress range; 795 psi to 2,420 psi.

Amplitude determinations were made in the manner described in Chapter III, section 2, using composite curves for each test; figures 20-25.

The maximum fiber stress was obtained as follows:

a. Amplitude of motion was determined for a given cycle at the condenser, a point 5.0 inches from the fixed end.

b. Amplitude of motion at the end of the cantilever for this cycle was obtained using equation 3, appendix, which gives:

$$y_1 = \frac{y}{0.7963}$$

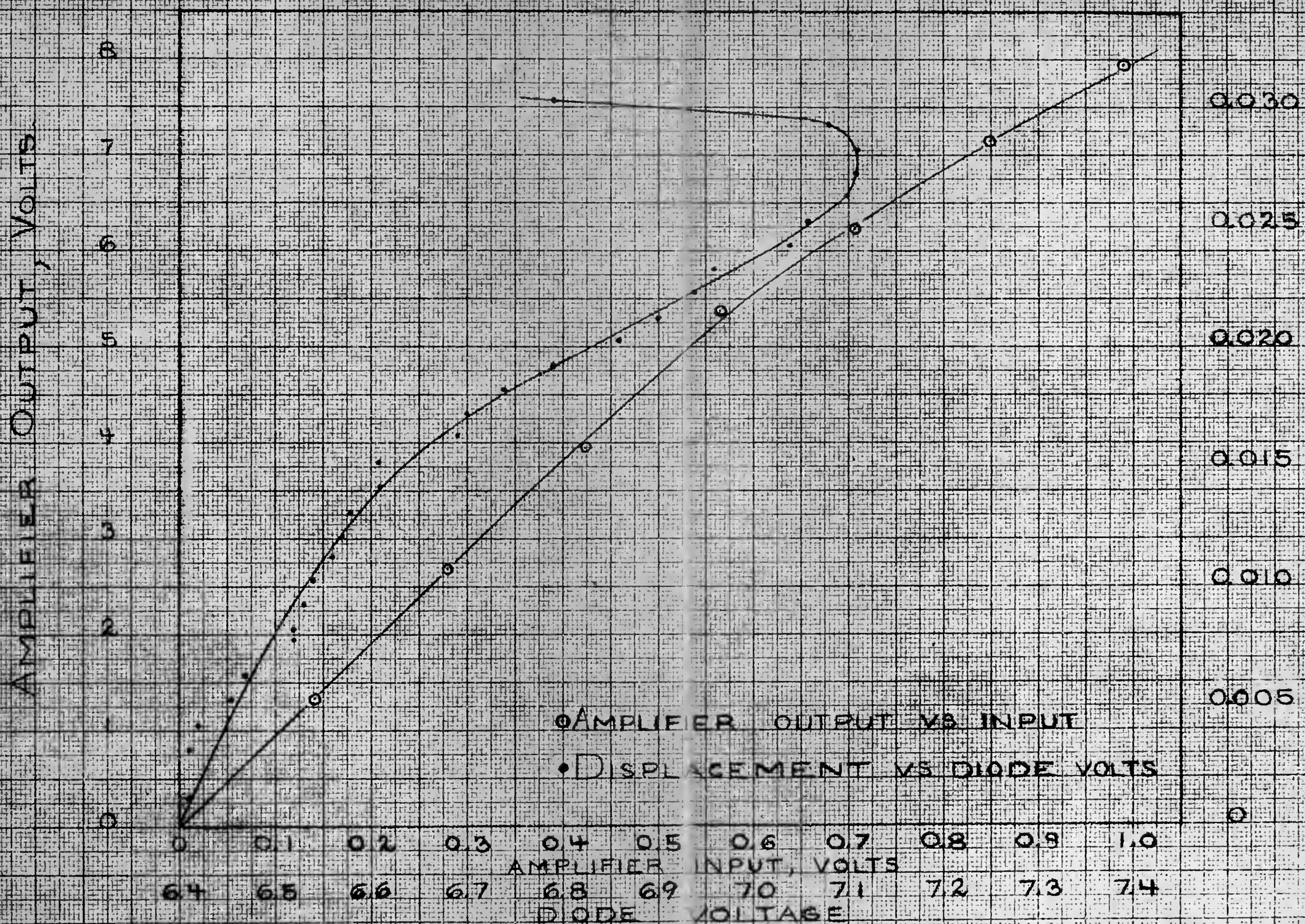
c. Maximum fiber stress was found using the amplitude at the free end from:

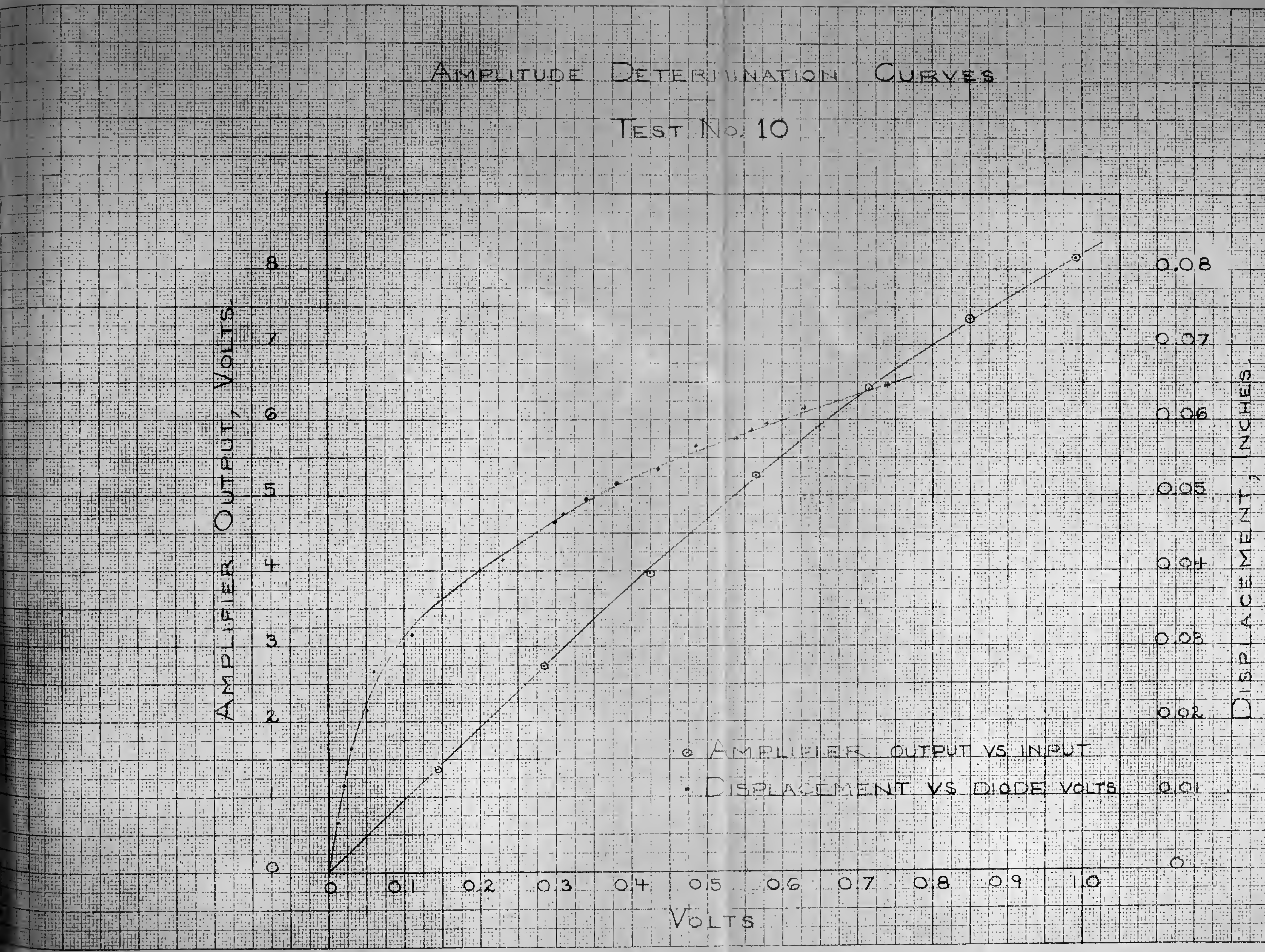
$$\Delta_1 = 1.00256 E h p^2 y_1 \qquad (2)$$

where pl - 1.875 for the first mode, Kimball (6)

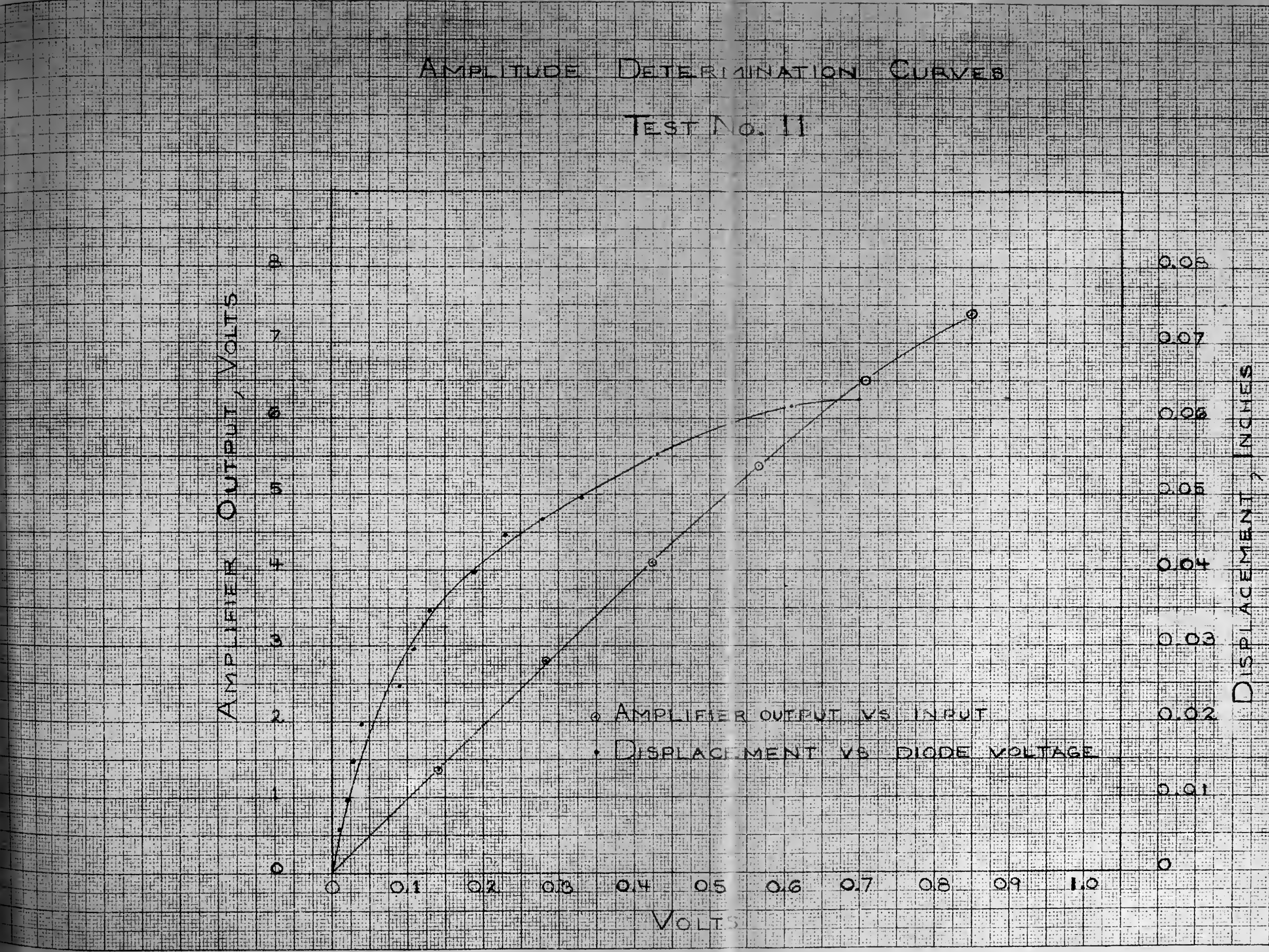
AMPLITUDE DETERMINATION CURVES

TEST No. 9





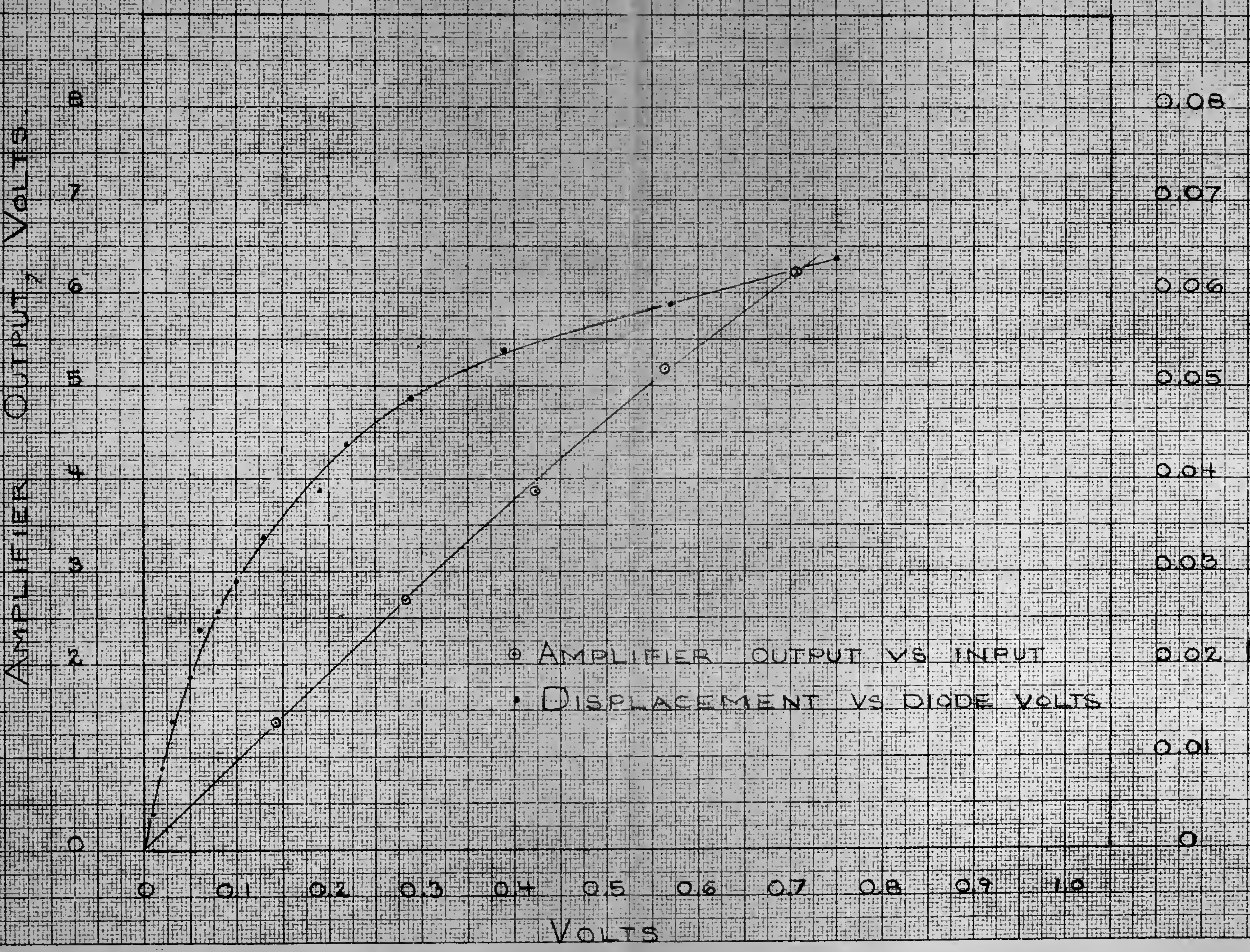
AMPLITUDE DETERMINATION CURVES
TEST NO. 10
AMPLIFIER OUTPUT, VOLTS
DISPLACEMENT, INCHES
0
1
2
3
4
5
6
7
8
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
VOLTS
AMPLIFIER OUTPUT VS INPUT
DISPLACEMENT VS DIODE VOLTS

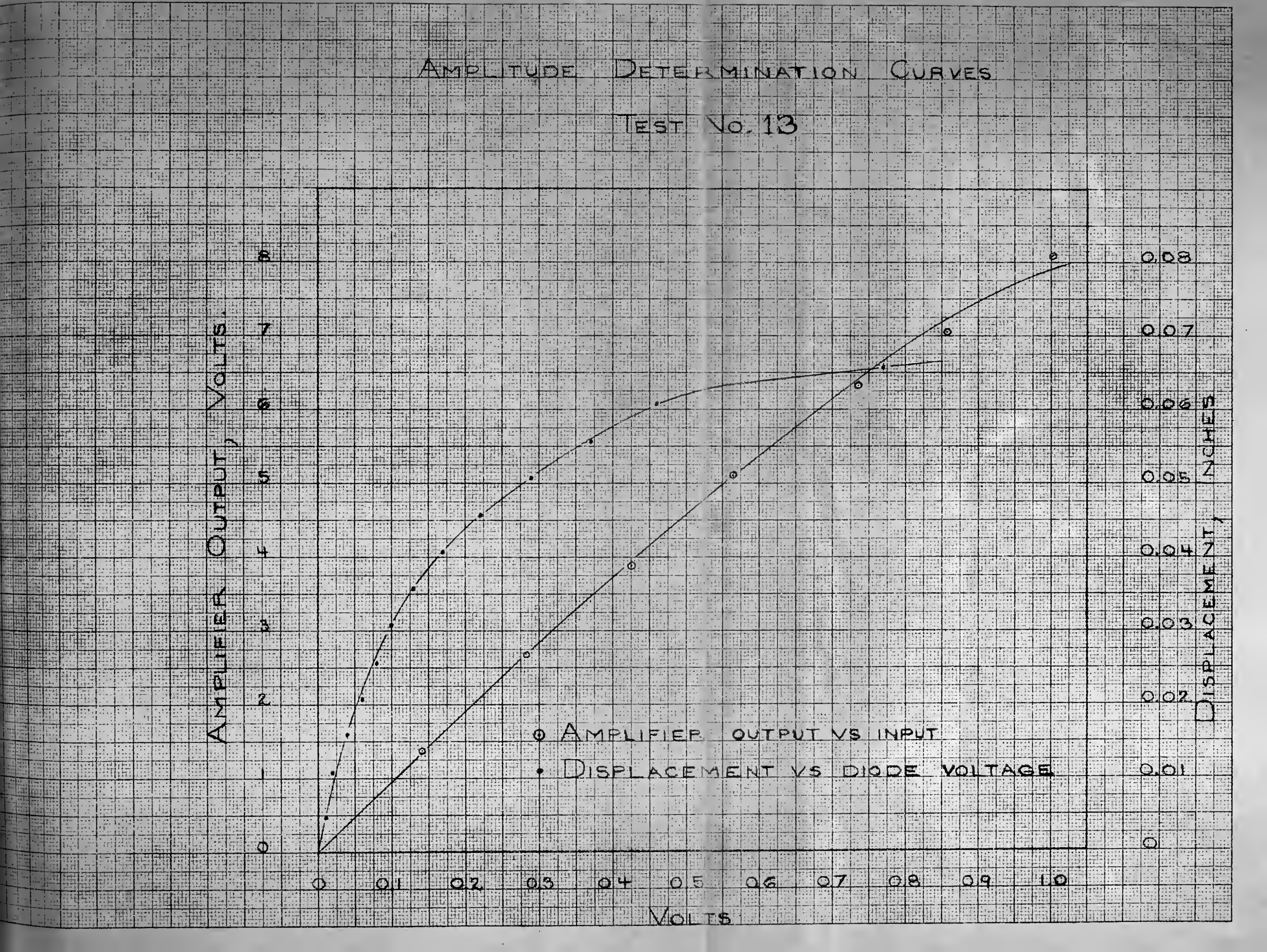


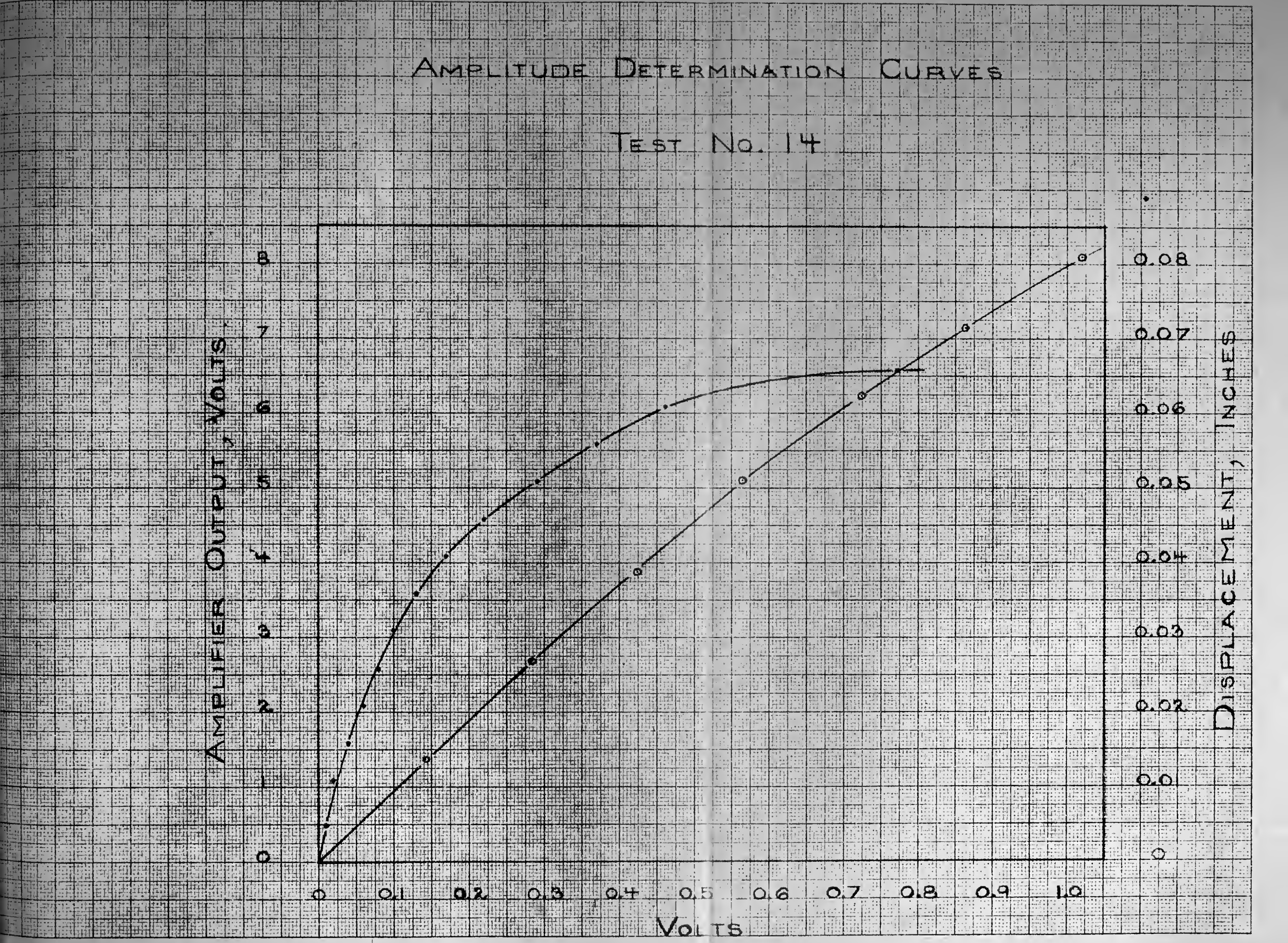
AMPLITUDE DETERMINATION CURVES
TEST NO. 11
AMPLIFIER OUTPUT, VOLTS
DISPLACEMENT, INCHES
VOLTS
8
7
6
5
4
3
2
1
0
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
AMPLIFIER OUTPUT VS INPUT
DISPLACEMENT VS DIODE VOLTAGE

AMPLITUDE DETERMINATION CURVES

TEST NO. 12




AMPLITUDE DETERMINATION CURVES
TEST NO. 13
AMPLIFIER OUTPUT, VOLTS
DISPLACEMENT, INCHES
VOLTS
0
1
2
3
4
5
6
7
8
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
AMPLIFIER OUTPUT VS INPUT
DISPLACEMENT VS DIODE VOLTAGE


AMPLITUDE DETERMINATION CURVES
TEST NO. 14
AMPLIFIER OUTPUT, VOLTS
DISPLACEMENT, INCHES
VOLTS
0
1
2
3
4
5
6
7
8
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

For the cantilever used, equation (2) gives

$$s_1 = 73,800\, y_1$$

Modes of vibration other than the first caused the motion to be slightly non-periodic with certain amplitudes being greater than those of the cycles immediately preceeding. To obtain a decriment under these circumstances the amplitude of a given cycle, y_n, was used as the average of amplitude y_{n-1} , y_n, and y_{n+1}.

2. Results.

Data obtained during the damping tests are presented in figures 26 to 32. Results of the tests, figures 33 to 38, are tabulated showing the following items: cycle identification, height of oscillograph trace above neutral axis for the given cycle, corresponding output voltage from the amplifier, amplitude of vibration as determined from figures 20 to 25, maximum fiber stress at x = 0 for the corresponding amplitude and cycle as obtained from formula (2), the logarithmic decriment between identified cycles obtained from formula (6), and the specific damping capacity. Figure 39 shows a plot of the specific damping capacity vs. maximum fiber stress for the various temperature tests, and figures 40-45 are copies of the oscillographs for the damping tests.

The following observations and conclusions are reached from these data:

a. Points on figure 39 are too widely dispersed to give extremely accurate results. This is presumed to be due to the various modes of vibration other than the first that are present and to the fact that the time for each half cycle

of a given cycle is not exactly equal. The former gives amplitudes of varying heights according to the various modes and the latter gives rise to some error in selecting the axis on the oscillograph trace.

b. Curves drawn through the points indicate a slight increase in damping capacity with stress. As discussed in the appendix, damping increases only a small amount with stress in the low stress region. Also, owing to the stress distribution, only a small portion of the cantilever is stressed to significant magnitudes. Accordingly, only a small increase in damping with stress in the region tested is to be expected.

c. Damping increased with temperature initially; the highest damping being for test number 12 at sample free end-fixed end temperature of 278-167 degrees F. For greater temperatures tested the damping decreased to approximately the room temperature value. As mentioned in the appendix, a maximum is to expected and the temperature at which the maximum occurred is reasonable. It is considered that the fixed end temperature, where the highest stresses occur, influences the damping capacity to a greater extent than the free end temperature. No attempt was made to evaluate the temperature gradient along the sample or the variable stress distribution and correlate their proportional effect on the overall damping of the cantilever.

d. Test results of two other investigations follows for

comparison:

Investigator: Contractor and Thompson (2).

Metal: 0.2% carbon steel, hot rolled.

Method: Torsional.

Stress: 4,000 psi maximum

Temperature range: 68-302 degrees F.

Specific damping capacity range (approximate) 0.019-0.033

Temperature for maximum damping 230 degrees F.

Investigator: Schabtach and Fehr (12).

Material: SAE 1020 steel

Method: Tuning fork.

Stress: 5000 psi.

Temperature range: 75-500 degrees F.

Specific damping capacity range: 0.0022-0.006

Temperature for maximum damping: Approximate 300 degrees F.

Low values of damping in these results indicate support losses in the author's testing machine.

e. It is considered that the amplitude pickup and associated equipment provides an extremely accurate method of measuring amplitudes of motion. This is indicated by the character of the data obtained and the fact that the second mode of vibration showed clearly on the oscillograph trace.

FIGURE 26

DAMPING TEST DATA

Amplifier Output vs Input Voltage at 48 cycles/second

Test Number	Input voltage Volts (Max.)	Output voltage Volts (Max.)
	0.1414	1.342
	0.2828	2.690
9	0.4242	3.950
	0.5656	5.370
	0.7070	6.220
	0.8500	7.150
	0.9910	7.950
	0.1414	1.360
	0.2828	2.73
10	0.4242	3.98
	0.5656	5.26
	0.7150	6.40
	0.8500	7.34
	0.9900	8.17
	0.1414	1.36
	0.2828	2.80
	0.4242	4.10
	0.5656	5.37
11	0.7070	6.50
	0.8500	7.37
	0.9900	8.42
	0.1414	1.36
	0.2828	2.69
	0.4242	3.86
	0.5656	5.16
12	0.7070	6.23
	0.8500	7.36
	0.992	8.07
	0.1414	1.37
	0.2828	2.69
	0.4242	3.88
13	0.5656	5.10
	0.736	6.30
	0.856	7.08
	1.02	8.10

FIGURE 26 (Contd.)

Amplifier Output vs Input Voltage at 48 cycles/second

Test Number	Input voltage Volts (Max.)	Output voltage Volts (Max.)
	.1414	1.37
	.2828	2.69
14	.4242	3.88
	.5656	5.10
	.723	6.23
	.865	7.15
	1.02	8.10

FIGURE 27

DAMPING TEST DATA

Test No. 9

Temperature of sample	78 deg. F.
Room temperature	78 deg. F.
Barometer	29.55 In. Hg.
Vacuum	22.5 In. Hg.

STATIC CALIBRATION

Corrected voltage across diode output	Dial gage reading	
Volts	Inches	
6.40	0.2682	Zero displacement
6.41	0.2670	
6.41	0.2650	
6.42	0.2640	
6.46	0.2630	
6.47	0.2620	
6.52	0.2605	
6.52	0.2600	
6.53	0.2590	
6.54	0.2580	
6.56	0.2570	
6.57	0.2560	
6.58	0.2550	
6.61	0.2540	
6.61	0.2530	
6.69	0.2520	
6.70	0.2510	
6.74	0.2500	
6.79	0.2490	
6.86	0.2480	
6.90	0.2470	
6.94	0.2460	
6.96	0;2450	
7.04	0.2440	
7.06	0.2430	
7.10	0.2420	
7.11	0.2410	
7.11	0.2400	
7.08	0.2390	
6.79	0.2380	
	0.2332	Sample touched condenser

FIGURE 28

DAMPING TEST DATA

Test No. 10

Temperature of sample	78 deg. F.
Room temperature	78 deg. F.
Barometer	29.82 In. Hg.
Vacuum	20.0 In. Hg.

STATIC CALIBRATION

Corrected voltage across diode output	Dial gage reading	
Volts	Inches	
5.96	0.3715	Zero displacement
5.97	0.3650	
5.98	0.3600	
5.99	0.3550	
6.01	0.3500	
6.02	0.3450	
6.07	0.3400	
6.10	0.3350	
6.19	0.3300	
6.26	0.3250	
6.27	0.3240	
6.30	0.3220	
6.34	0.3200	
6.45	0.3150	
6.40	0.3180	
6.50	0.3140	
6.52	0.3130	
6.54	0.3120	
6.59	0.3100	
6.70	0.3075	
6.76	0.3060	
6.88	0.3040	
6.88	0.3030	
6.95	0.3020	
7.08	0.3010	
7.11	0.3000	
7.20	0.2980	
7.06	0.2972	
	0.2970	Sample touched condenser

FIGURE 29

DAMPING TEST DATA

Test No. 11

Temperature of sample at free end	146 deg. F.
Temperature of sample at base	100 deg. F.
Barometer	30.03 In. Hg.
Vacuum	19.0 In. Hg.

STATIC CALIBRATION

Corrected voltage across diode output	Dial gage reading	
Volts	Inches	
5.89	0.2846	Zero displacement
5.90	0.2790	
5.91	0.2750	
5.92	0.2700	
5.93	0.2650	
5.98	0.2600	
6.00	0.2550	
6.02	0.2500	
6.08	0.2450	
6.12	0.2400	
6.22	0.2350	
6.32	0.2300	
6.42	0.2250	
6.50	0.2220	
6.61	0.2210	
6.68	0.2200	
6.80	0.2170	
6.88	0.2150	
6.95	0.2140	
6.67	0.2130	
7.03	0.2120	
6.95	0.2110	
-	0.2104	Sample touched condenser

FIGURE 30

DAMPING TEST DATA

Test No. 12

Temperature of sample at free end	278 deg. F.
Temperature of sample at base	120 Deg. F.
Barometer	30.05 In. Hg.
Vacuum	20.5 In. Hg.

STATIC CALIBRATION

Corrected voltage across diode output	Dial gage reading	
Volts	Inches	
5.23	0.3138	Zero displacement
5.24	0.3100	
5.25	0.3050	
5.26	0.3000	
5.28	0.2950	
5.29	0.2900	
5.31	0.2880	
5.33	0.2850	
5.36	0.2800	
5.42	0.2750	
5.45	0.2700	
5.52	0.2650	
5.62	0.2600	
5.80	0.2550	
5.98	0.2500	
6.29	0.2450	
6.40	0.2440	
6.51	0.2430	
6.61	0.2420	
6.79	0.2410	
6.82	0.2400	
-	0.2392	Sample touched condenser

FIGURE 31

DAMPING TEST DATA

Test No. 13

Temperature of sample at free end	699 deg. F.
Temperature of sample at base	204 deg. F.
Barometer	29.96 In. Hg.
Vacuum	13.0 In. Hg.

STATIC CALIBRATION

Corrected voltage across diode output	Dial gage reading	
Volts	Inches	
4.58	0.3509	Zero displacement
4.59	0.3460	
4.60	0.3400	
4.62	0.3350	
4.64	0.3300	
4.66	0.3250	
4.68	0.3200	
4.71	0.3150	
4.75	0.3100	
4.80	0.3050	
4.87	0.3000	
4.95	0.2950	
5.04	0.2900	
5.35	0.2850	
5.85	0.2800	
6.20	0.2780	
-	0.2770	Sample touched condenser

FIGURE 32

DAMPING TEST DATA

Test No. 14

Temperature of sample at free end	484 deg. F.
Temperature of sample at base	158 deg. F.
Barometer	29.70 In. Hg.
Vacuum	16.0 In. Hg.

STATIC CALIBRATION

Corrected voltage across diode output	Dial gage reading	
Volts	Inches	
		Zero displacement
4.78	0.2642	
4.80	0.2600	
4.81	0.2550	
4.83	0.2500	
4.87	0.2450	
4.92	0.2400	
4.95	0.2350	
5.00	0.2300	
5.11	0.2250	
5.30	0.2200	
5.55	0.2150	
6.21	0.2095	Sample touched condenser

FIGURE 33

DAMPING TEST RESULTS

Test No. 9

Temperature of sample	78 deg. F
Absolute pressure	7.05 In. Hg.
Frequency of sample	48 cycles per second

Cycle Number	Measured height, inches	Amplifier output voltage, volts	Amplitude of vibration, inches	Maximum fiber stress P.S.I.	Log. decriment	Specific damping capacity
0	1.34	6.18	0.0261-	2420		
					0.0067	0.013
10	1.24	5.72	0.0244	2265		
					0.0041	0.008
20	1.17	5.40	0.0234	2170		
					0.0049	0.010
30	1.08	4.98	0.0222	2060		
					0.0058	0.012
40	0.96	4.43	0.0209	1940		
					0.0041	0.008
50	0.87	4.02	0.0200	1865		
					0.0041	0.008
60	0.80	3.70	0.0192	1780		
					0.0041	0.008
70	0.73	3.37	0.0184	1708		
					0.0032	0.006
80	0.68	3.14	0.0178	1655		
					0.0058	0.012
90	0.61	2.82	0.0168	1560		
					0.0037	0.007
100	0.57	2.63	0.0162	1510		
					0.0064	0.013
115	0.48	2.22	0.0147	1365		
					0.0062	0.012
130	0.41	1.89	0.0132	1226		
					0.0042	0.008
145	0.37	1.71	0.0124	1150		
					0.0044	0.009
160	0.34	1.57	0.0116	1080		
					0.0059	0.012
180	0.29	1.34	0.0103	954		
					0.0089	0.018
200	0.23	1.06	0.0086	795		

FIGURE 34

DAMPING TEST RESULTS

Test No. 10

Temperature of sample	78 deg. F.
Absolute pressure	9.82 In. Hg.
Frequency of sample	48 cycles per second

Cycle Number	Measured height, Inches	Amplifier output voltage, Volts	Amplitude of Vibration, Inches	Maximum fiber stress, P.S.I.	Log. decriment	Specific damping capacity
0	1.15	5.30	0.0590	5460		
					0.0079	0.016
10	0.93	4.28	0.0545	5050		
					0.0049	0.010
20	0.81	3.73	0.0520	4820		
					0.0079	0.016
30	0.67	3.09	0.0480	4450		
					0.0079	0.016
40	0.55	2.54	0.0442	4090		
					0.0052	0.010
60	0.41	1.89	0.0398	3680		
					0.0029	0.006
80	0.34	1.57	0.0375	3480		
					0.0070	0.014
100	0.26	1.20	0.0325	3010		
					0.0024	0.005
120	0.23	1.06	0.0310	2870		
					0.0059	0.012
140	0.19	0.876	0.0275	2550		
					0.0056	0.011
160	0.16	0.738	0.0245	2270		
					0.0043	0.009
180	0.14	0.645	0.0225	2080		

FIGURE 35

DAMPING TEST RESULTS

Test No. 11

Temperature of sample at free end	146 deg. F.
Estimated temperature of sample at 0.1 inch from fixed end	108 deg. F.
Absolute pressure	11.03 In.Hg.
Frequency of sample	47.8 cycles per second

Cycle Number	Measured height	Amplifier output voltage,	Amplitude of Vibration	Maximum fiber stress	Log. decriment	Specific damping capacity
	Inches	Volts	Inches	P.S.I.		
0	1.08	4.98	0.0590	5460		
					0.0060	0.012
10	0.91	4.20	0.0555	5140		
					0.0095	0.019
20	0.72	3.32	0.0505	4670		
					0.0077	0.015
30	0.59	2.72	0.0468	4340		
					0.0084	0.017
40	0.47	2.17	0.0430	3980		
					0.0068	0.014
50	0.40	1.85	0.0402	3720		
					0.0082	0.016
60	0.33	1.52	0.0370	3420		
					0.0043	0.009
80	0.28	1.29	0.0340	3150		
					0.0070	0.014
100	0.21	0.97	0.0295	2730		
					0.0059	0.012
120	0.15	0.692	0.0235	2180		

FIGURE 36

DAMPING TEST RESULTS

Test No. 12

Temperature of sample at free end	278 deg. F.
Estimated temperature of sample at 0.1 inch from fixed end	167 deg. F.
Absolute pressure	9.55 In.Hg.
Frequency of sample	47.8

Cycle Number	Measured height	Amplifier output voltage,	Amplitude of Vibration	Maximum fiber stress	Log. decriment	Specific damping capacity
	Inches	Volts	Inches	P.S.I.		
0	1.15	5.31	0.0591	5475		
					0.0082	0.016
10	0.85	3.92	0.0545	5050		
					0.0086	0.017
20	0.65	3.00	0.0500	4630		
					0.0124	0.025
30	0.47	2.17	0.0441	4090		
					0.0086	0.017
40	0.39	1.80	0.0405	3750		
					0.0104	0.021
50	0.32	1.48	0.0365	3380		
					0.0095	0.019
60	0.27	1.25	0.0330	3060		
					0.0081	0.016
80	0.20	0.922	0.0280	2565		
					0.0112	0.022
100	0.14	0.645	0.0224	2080		
					0.0120	0.024
120	0.10	0.462	0.0175	1620		

FIGURE 37

DAMPING TEST RESULTS

Test No. 13

Temperature of sample at free end	699 deg. F.
Estimated temperature of sample at 0.1 inch from fixed end	355 deg. F.
Absolute pressure	16.96 In. Hg.
Frequency of sample	46.4 cycles per second

Cycle Number	Measured height	Amplifier output voltage	Amplitude of Vibration	Maximum fiber stress	Log. decriment	Specific damping capacity
	Inches	Volts	Inches	P.S.I.		
0	1.29	5.95	0.0647	6000		
					0.0020	0.004
10	1.13	5.22	0.0635	5870		
					0.0067	0.013
20	0.87	4.02	0.0593	5500		
					0.0082	0.016
30	0.71	3.28	0.0547	5070		
					0.0060	0.012
40	0.61	2.82	0.0514	4760		
					0.0058	0.012
50	0.53	2.45	0.0485	4500		
					0.0037	0.007
70	0.44	2.03	0.0450	4170		
					0.007	0.014
90	0.32	1.48	0.0391	3620		
					0.0070	0.014
110	0.24	1.11	0.0341	3160		
					0.0040	0.008
130	0.21	0.97	0.0315	2920		
					0.0070	0.014
150	0.17	0.785	0.0274	2540		

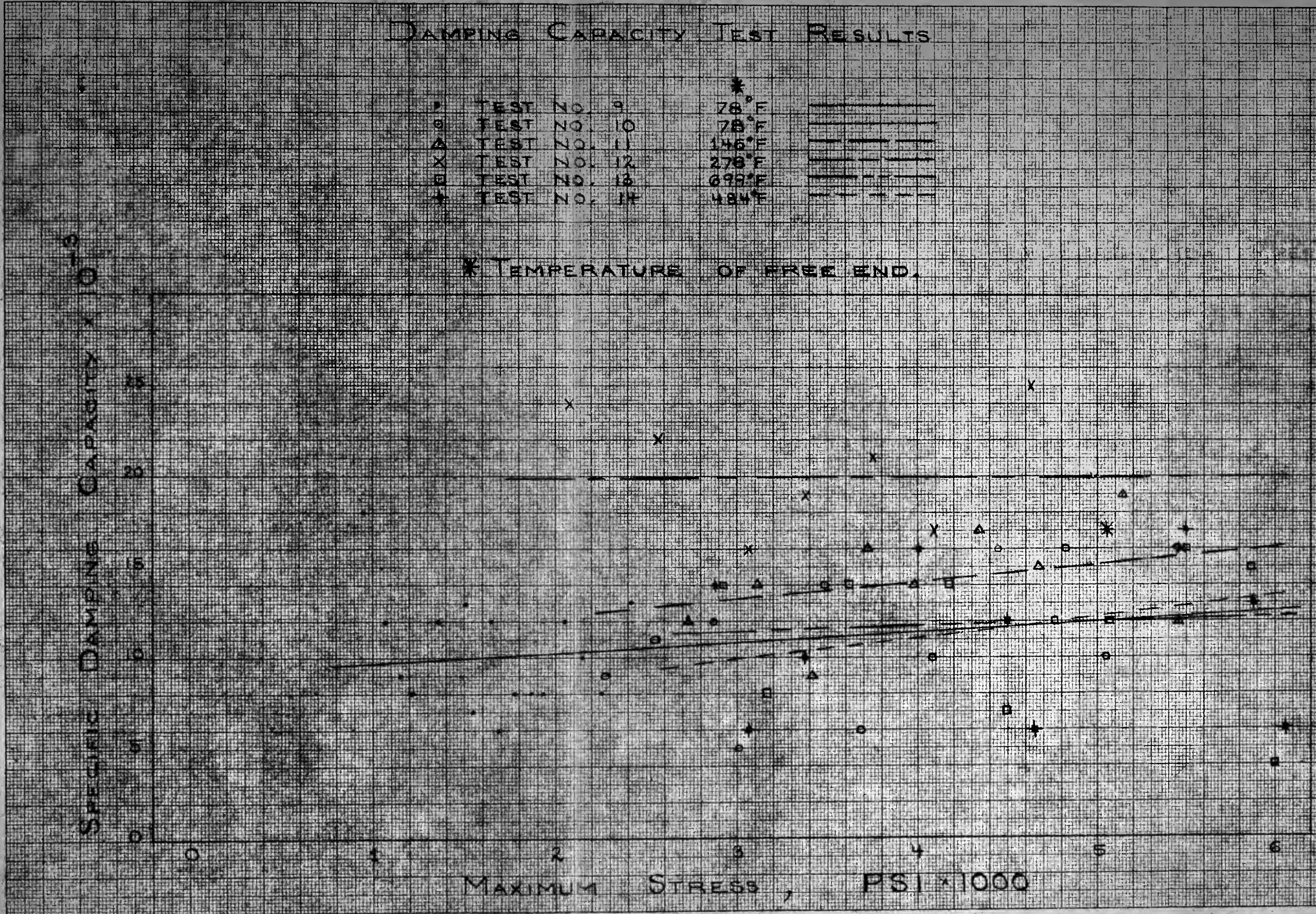
FIGURE 38

DAMPING TEST RESULTS

Test No. 14

Temperature of sample at free end	484 deg. F.
Estimated temperature of sample at 0.1 inch from fixed end	260 deg. F.
Absolute pressure	13.7 In. Hg.
Frequency of sample	47.0 cycles per second

Cycle Number	Measured height	Amplifier output voltage	Amplitude of Vibration	Maximum fiber stress	Log. decriment	Specific damping capacity
	Inches	Volts	Inches	P.S.I.		
0	1.33	6.15	0.0655	6060		
					0.0030	0.006
10	1.09	5.03	0.0635	5880		
					0.0063	0.013
20	0.87	4.02	0.0595	5500		
					0.0086	0.017
30	0.70	3.23	0.0545	5050		
					0.0083	0.017
40	0.57	2.64	0.0502	4650		
					0.0032	0.006
50	0.53	2.45	0.0487	4500		
					0.0061	0.012
70	0.39	1.80	0.0431	4000		
					0.0082	0.016
90	0.28	1.29	0.0366	3380		
					0.0052	0.010
110	0.23	1.06	0.0330	3060		
					0.0029	0.006
130	0.21	0.97	0.0312	2890		
					0.0068	0.014
150	0.17	0.785	0.0272	2520		



DAMPING CAPACITY TEST RESULTS
*
TEST NO. 9 78°F
TEST NO. 10 78°F
TEST NO. 11 146°F
TEST NO. 12 278°F
TEST NO. 13 699°F
TEST NO. 14 484°F
* TEMPERATURE OF FREE END.
SPECIFIC DAMPING CAPACITY × 10⁻³
25
20
15
10
5
0
0
1
2
3
4
5
6
MAXIMUM STRESS, PSI × 1000

3. Recommendations

It is considered that the following modifications would improve the performance of the testing machine:

a. Substitution of an air actuated bellows or piston for the magnetic solenoid to avoid insulation failure at temperatures over 200 degrees F.

b. Reduction of sample width to preclude possible torsional vibration.

c. Provide slight relief of sample support block grip surfaces below top edge to eliminate any damping at the fixed end.

d. Place condenser plate at 0.2261 from end of cantilever to eliminate second mode.

e. For high temperature investigations replace present glass wool-aluminum foil furnace insulation which has a maximum temperature limit of 1000 degrees F.

f. Provide heating coils for support blocks.

Figure [illegible]

[illegible]

fog 10

Figure 40

Leg 40

Figure 40

Figure 40

Figure 40

fcg 40

Figure 40

[illegible]

[illegible]

Figure 40

Figure 40

[illegible] 110

Figure 40

fig 40

Figure 41

Figure 41

Figure 41

Figure 41

Leg 41

Figure 11

Leg 41

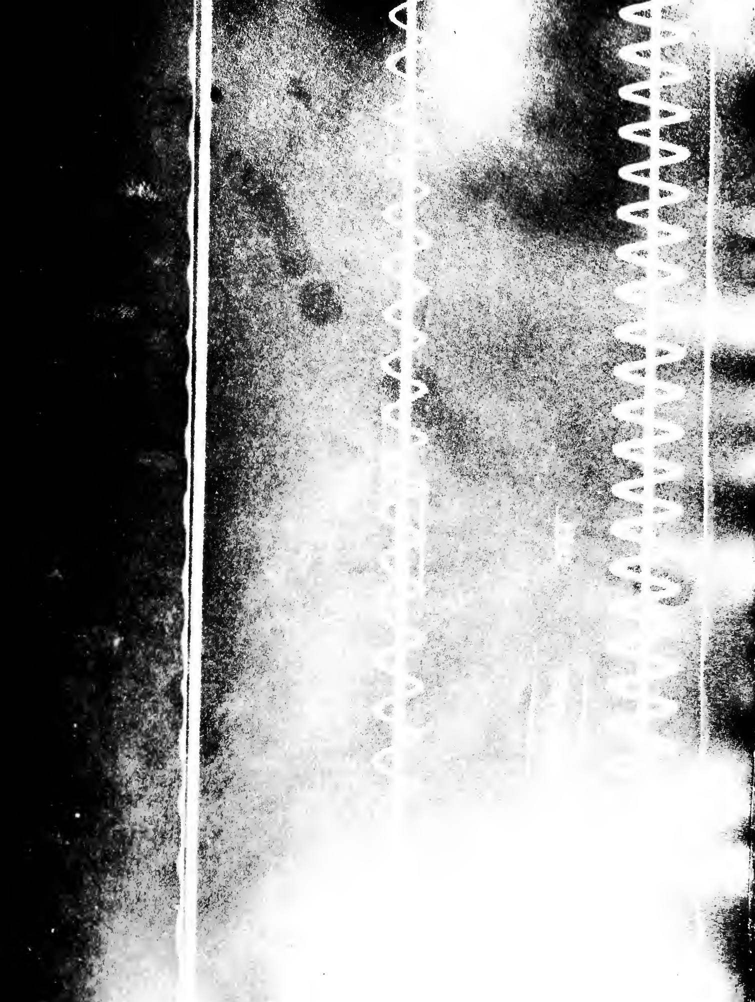


Figure 41

[illegible]

Volume 41
77

409

Figure 41

Figure 41

Figure 41

Leg 10

[illegible]

Figure 42

[illegible]

[illegible]

[illegible]

igure 42

fig 42

[illegible]

fig 13

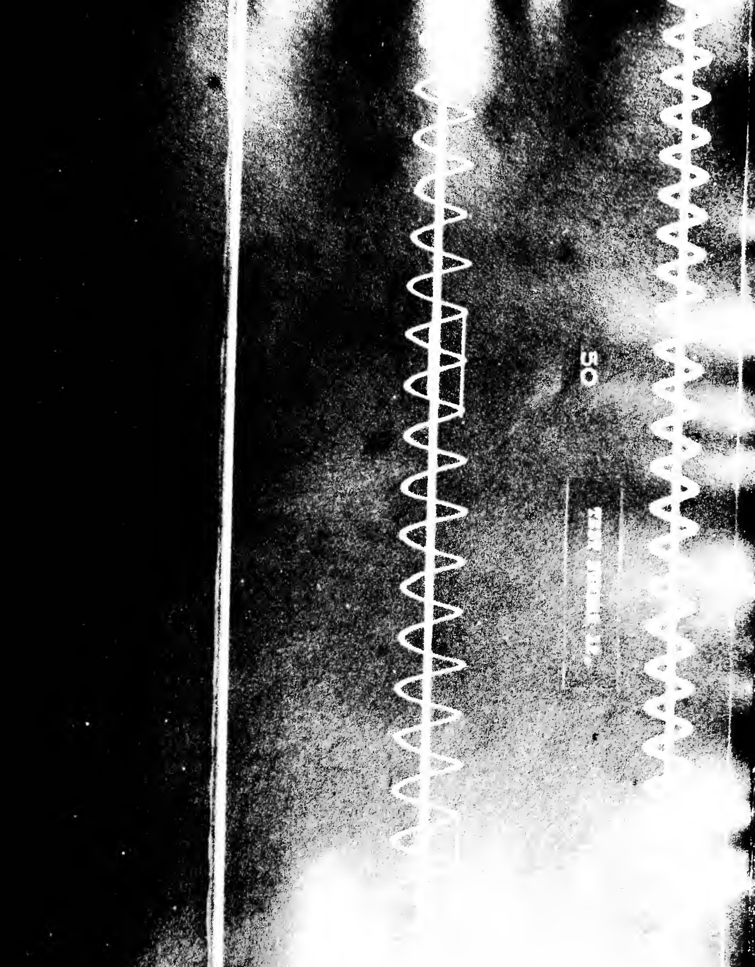


Figure 43

fig 12

[illegible]

Figure 45

fig 43

Figure 43

[illegible]

Figure 44

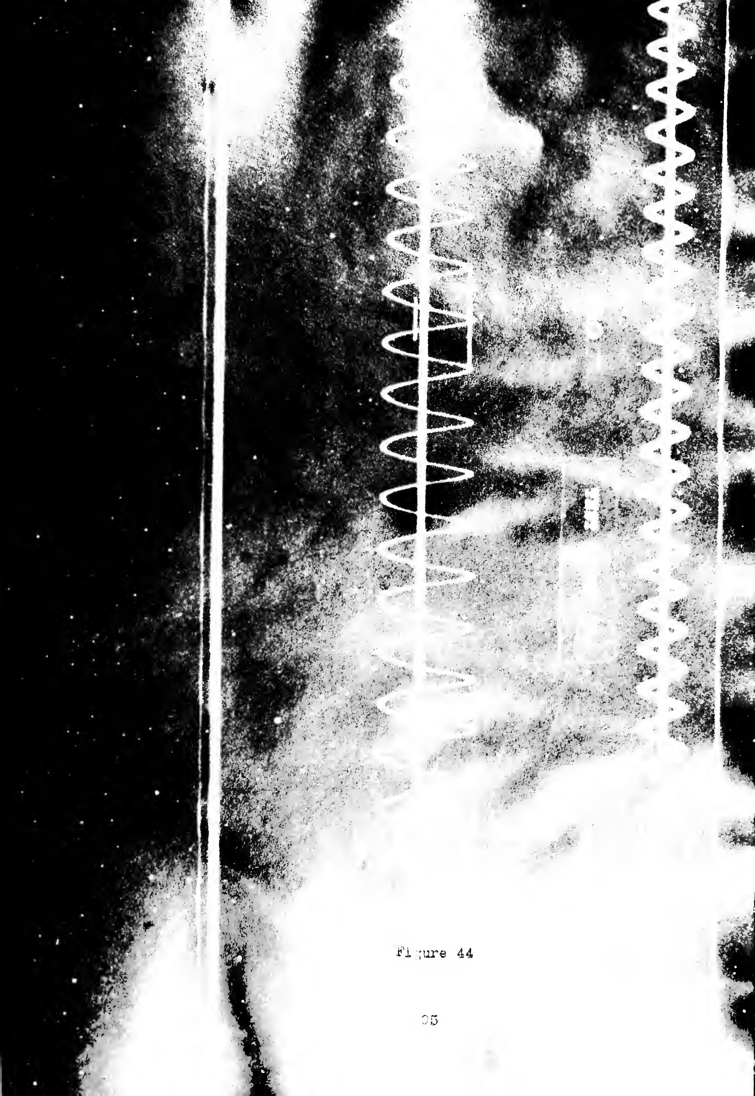


Figure 44

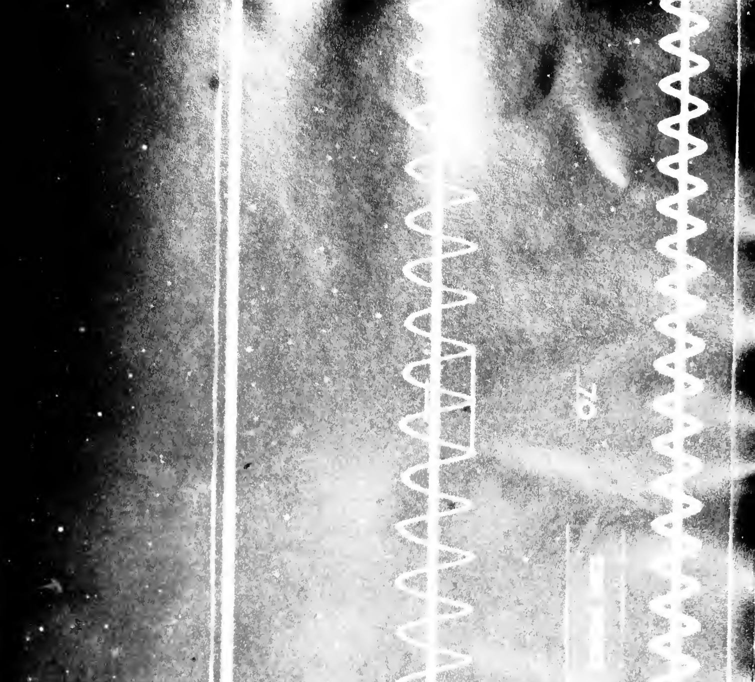
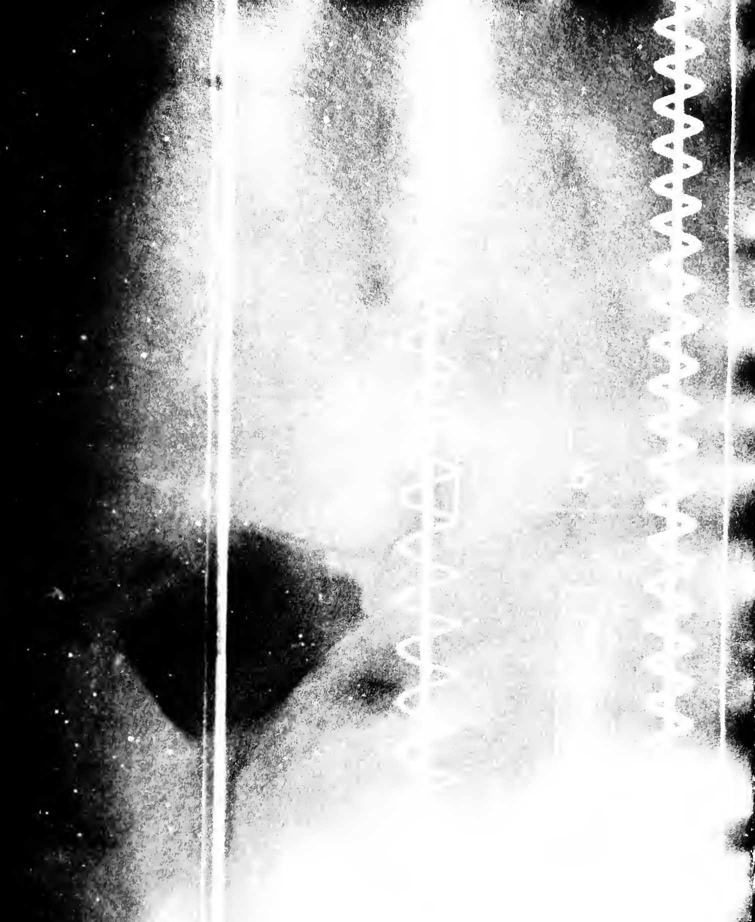


Figure 44



Fi re 44

Sey 44

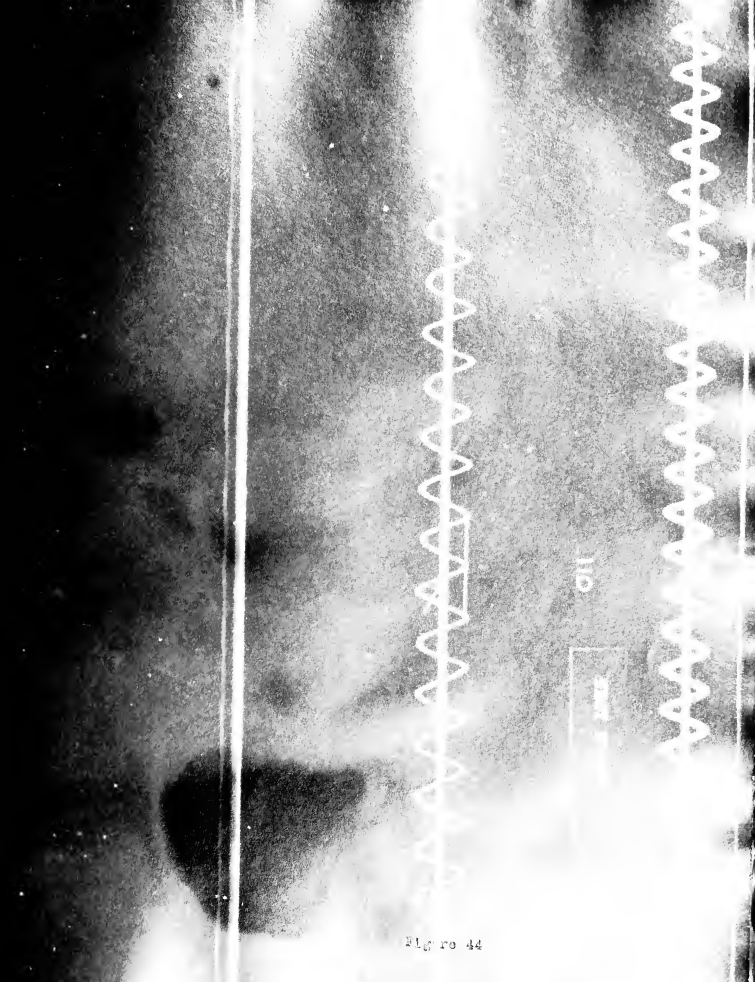


Figure 44

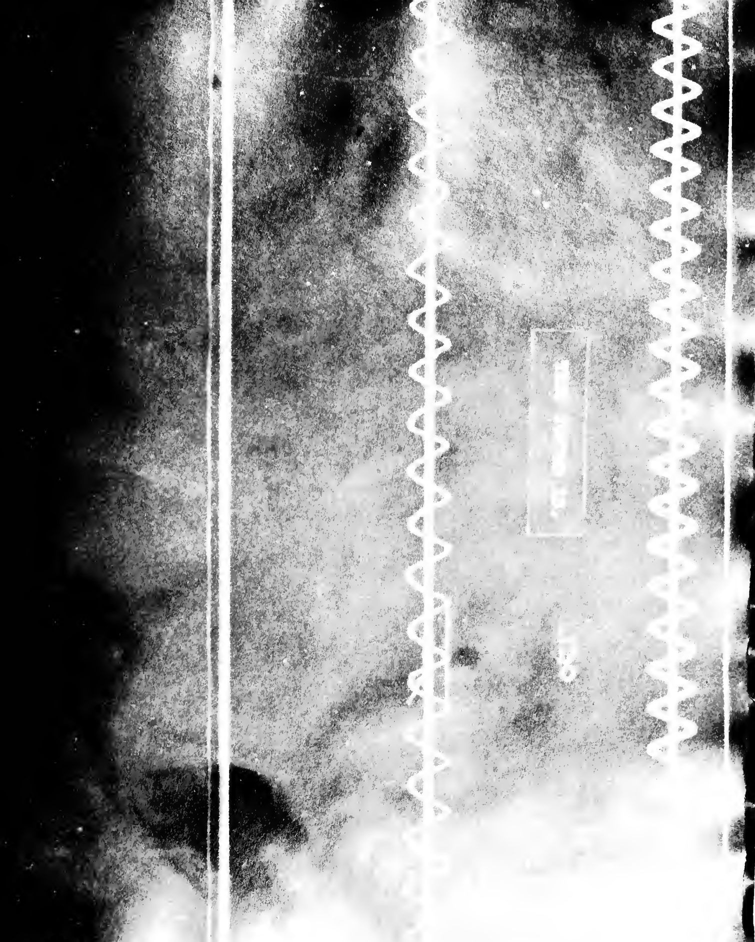


Figure 44

Figure 44

[illegible]

Figure 45

[illegible]

Figure 45

fcg 115

Figure 45

[illegible]

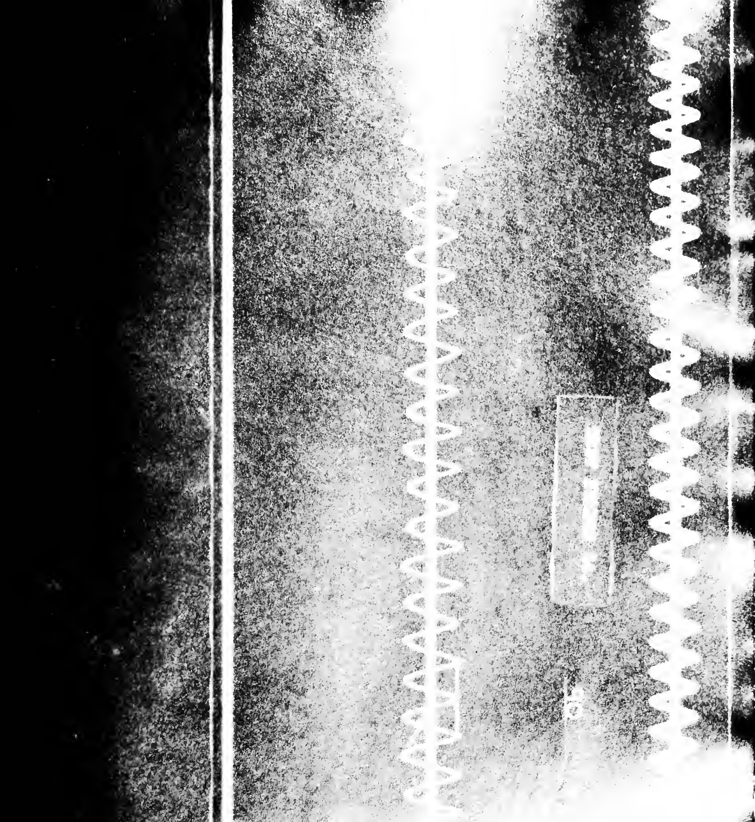


Figure 45

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APPENDIX

1. Damping formulae.

The property of damping may be expressed in several ways, the most popular being logarithmic decriment, damping capacity, and specific damping capacity. In this investigation the unit specific damping capacity has been used and is defined as the ratio $\frac{\Delta e}{e}$.

Determination of this ratio for many systems and in particular for a freely vibrating cantilever is readily accomplished by measurement of the logarithmic decriment which is shown to be one-half the Specific Damping Capacity.

The familiar expression for the first mode deflection curve of a cantilever beam in free vibration is given by Kimball (6) as:

$$y = y_1 \,(0.50128 \cosh px - 0.36806 \sinh px - 0.50128 \cos px + 0.36806 \sin px) \qquad (3).$$

$$pl = 1.875$$

Potential energy of a vibrating beam is

$$P = \frac{EI}{2}\int_0^l \left(\frac{d^2y}{dx^2}\right)^2 dx \qquad (4)$$

Den Hartog (4)

Substitution of equation (3) in (4) gives:

$$P = \frac{EI}{2} y_1^2 p^4 \int_0^l (0.50128 \cosh px - 0.36806 \sinh px + 0.50128 \cos px - 0.36806 \sin px)^2$$

Since in a cycle the energy changes from potential to kinetic and back again, this expression is sufficient to show that the total

energy in the cantilever is proportional to the amplitude square.

Kimball (6) shows that if $e = AY^2$

then $e - \Delta e = A(Y - \Delta Y)^2$

By squaring and dropping ΔY^2

$$\Delta e = 2AY\Delta Y$$

Therefore $\frac{\Delta e}{2e} = \frac{\Delta Y}{Y}$ (5)

By definition $\delta = ln \frac{Y_n}{Y_{n+1}}$

Therefore $\delta = ln\left(\frac{Y+\Delta Y}{Y}\right) = ln\left(1 + \frac{\Delta Y}{Y}\right)$

Expanding $\delta = \frac{\Delta Y}{Y} - \frac{\Delta Y^2}{2Y^2}$

and $\delta = \frac{\Delta Y}{Y}$ approximately

From equation (5) $\delta = \frac{\Delta Y}{Y} = \frac{\Delta e}{2e}$

Therefore $2\delta = \frac{\Delta e}{e} = D$

Den Hartog (4) shows that with one degree of freedom for damped free vibrations

$$Y_n = \epsilon^{-\delta f t}\left(A \cos \omega t + A_1 \sin \omega t\right)$$

Using the reasoning of Potter (9) on tonsional vibrations:

$$Y_{n+a} = \epsilon^{-\delta f\left(t + \frac{a}{f}\right)}\left(A \cos \omega t + A_1 \sin \omega t\right)$$

$$\frac{y_n}{y_{n+a}} = \frac{\epsilon^{-\delta f t}}{\epsilon^{-\delta f t} \cdot \epsilon^{-\delta a}} = \epsilon^{\delta a}$$

$$\ln\left(\frac{y_n}{y_{n+a}}\right) = \delta a$$

$$\text{and } \delta = \frac{1}{a} \ln\left(\frac{y_n}{y_{n+a}}\right) \qquad 6$$

Use of this equation assumes δ is constant over the range y_n to y_{n+a} for one mode.

2. Damping components and variables.

The solid friction of a material is made up of several components; the most important being the friction arising from plastic deformation and the vibrational energy loss due to irreversible thermal currents caused by the alternating stress.

The vibrational energy loss due to plastic deformation may be explained using the dislocation theory of Prandtl. Seitz (13). Atoms near the center of existing dislocations or dislocations caused by stress will move, owing to the alternating stress of vibration and irreversible work results. The amount of damping due to plastic deformation of a non-ferromagnetic metal depends on several variables as follows:

a. Stress amplitude. Damping capacity increases slightly with stress in the low stress range and increases greatly with high values of stress. Von Heydekampf (14), Hatfield (5), Schabtach (12).

b. Condition of anneal. Damping capacity decreases with increased annealing time and temperature. Annealing

below recrystallization temperature with no decrease in hardness will produce this effect. Seitz (13)

c. Temperature. Some polycrystalline metals such as aluminum, Zener (16), and 0.2 per cent carbon steel, Contractor (2), Schabtach (12), exhibit increasing damping with temperature. A maximum value occurs after which the damping capacity falls off as the temperature is increased. The frequency and the grain size are factors influencing the location of the maximum; the temperature for maximum damping being raised by increased grain size and frequency. Some metals, 0.9 per cent carbon steel and armco iron, exhibit steadily increased damping with temperature, Contractor (2), Hatfield (5).

Zener (16) has proven that internal friction may arise from the irreversible conversion of mechanical energy to heat between adjacent grains as well as between zones within the material. The magnitude of this thermoelastic internal friction for the former or microscopic case is a function of:

$$\frac{fb^2}{C}$$

$$\text{where } C = \frac{\text{Thermal Conductivity}}{\text{Specific Heat} \cdot \text{Density}}$$

For the latter or macroscopic case the damping is a function of

$$\frac{f \cdot \text{Distance}^2}{C} \qquad \text{Seitz (13)}$$

In each case the damping varies with frequency in such a manner that there is a frequency for which the damping is a maximum. When the configuration of the vibrating metal is such that the thermal gradient is steep, covering a large area such as in a thin reed in transverse vibration, the macroscopic thermal currents are a large contributing factor to the overall damping.

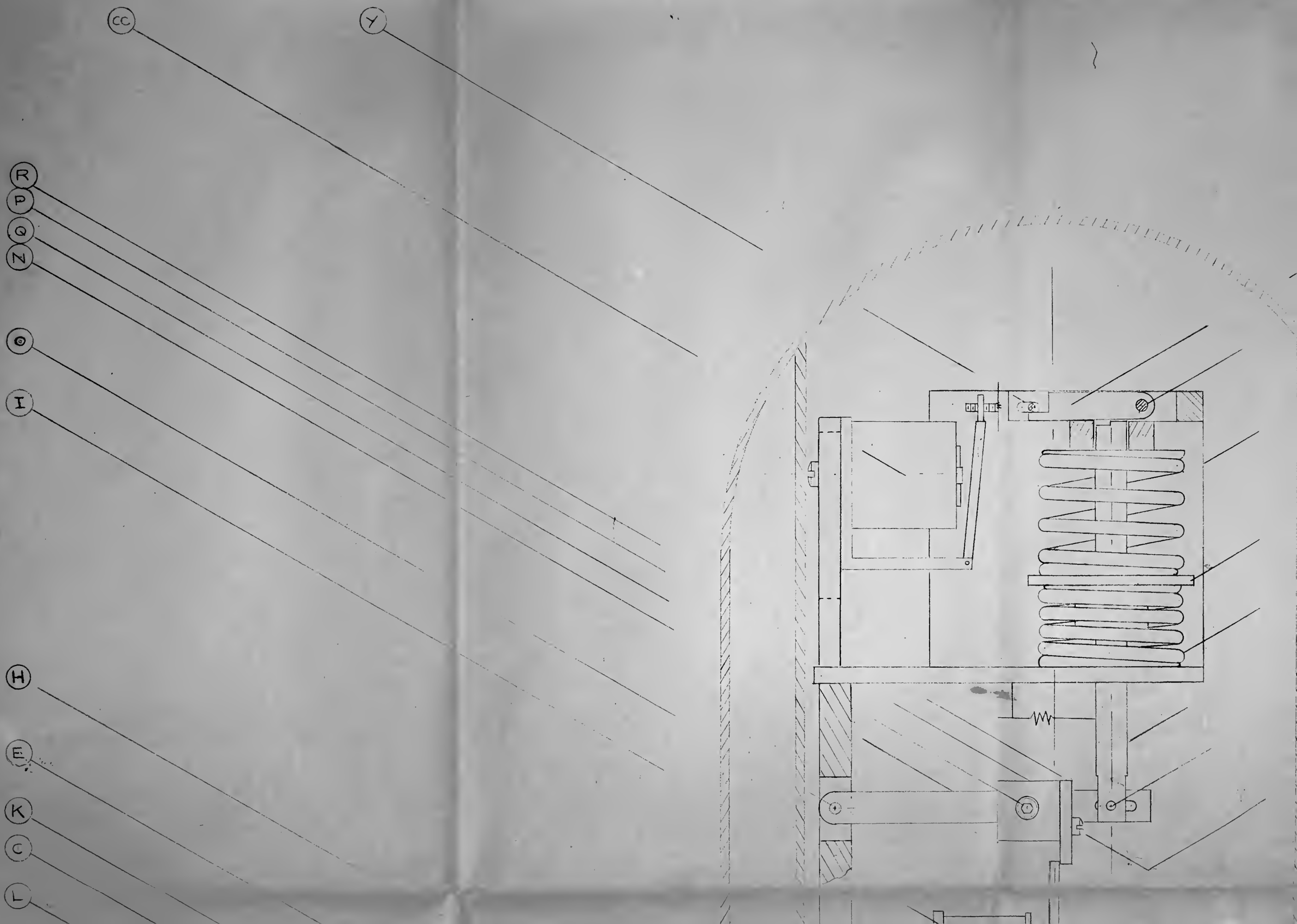
Ferromagnetic metals have a high damping capacity owing to eddy currents induced when magnetic domains are moved relative to one another. Increasing the magnetic saturation will decrease the damping.

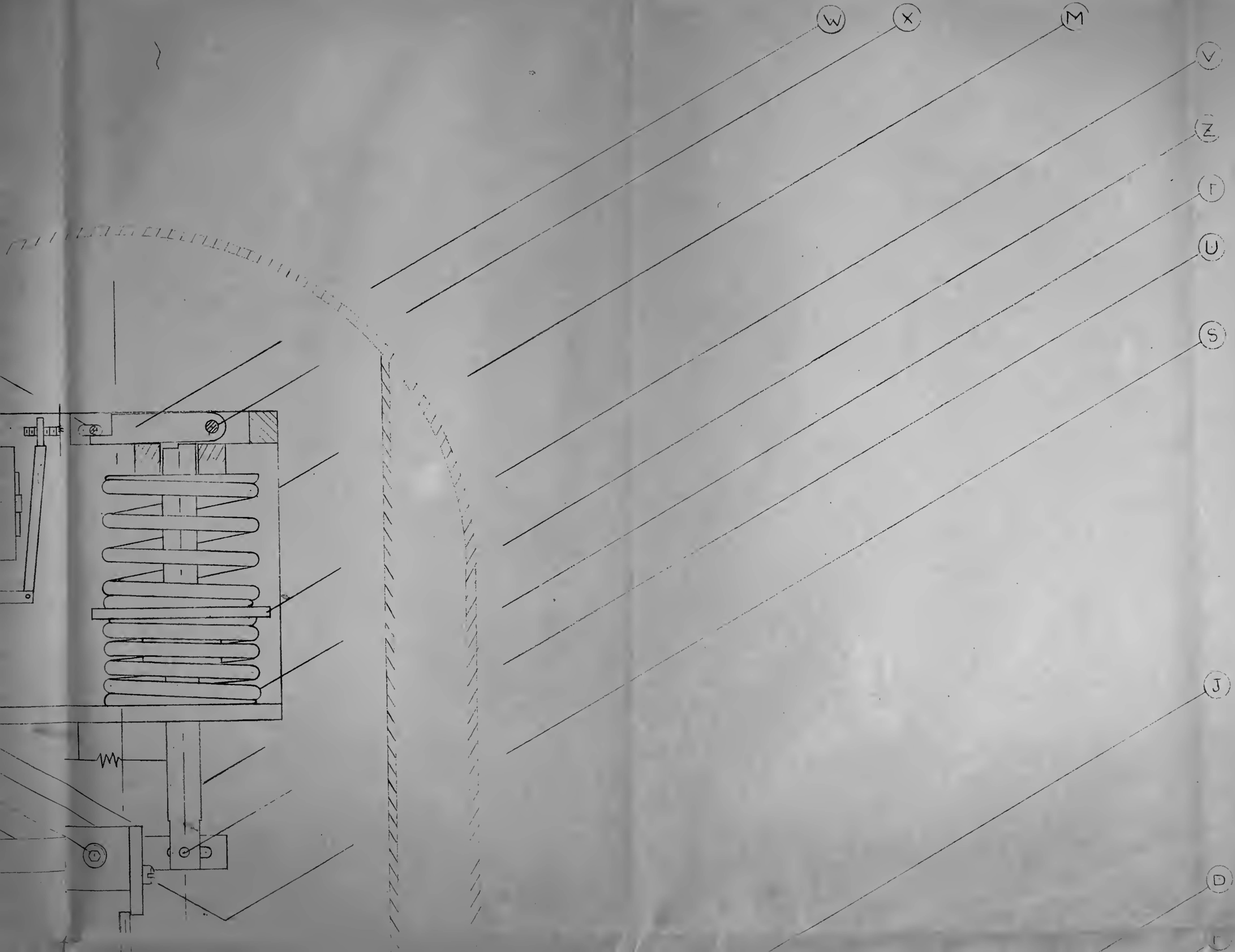
	BILL OF MATERIAL	NO.	
A	BASE PLATE LEGS	4	
B	CAP SCREWS	4	3/8 - [illegible] -2
C	SAMPLE SUPPORT BLOCK NO 1	1	
D	SAMPLE SUPPORT BLOCK NO 2	1	
E	CAP SCREWS	4	5/16 - 24 NF-2
F	STUD & NUT	2	5/16 - 18NC-2 : 24NF-2
G	BASE PLATE	1	
H	CONDENSER BRACKET	1	
I	CONDENSER	2	
J	SAMPLE	1	
K	RELEASE MECHANISM BASE	1	
L	CAP SCREWS	4	1/4 - 28 NF-2
M	RELEASE MECHANISM BRACKET	1	
	CAP SCREWS	2	5/16 - 24 NF-2
N	RELEASE LEVER	1	
O	PIN	1	
P	RELEASE ARM SUPPORT	1	
Q	SET SCREW	1	1/4 - 20NC-2
R	RELEASE ARM	1	
S	FILLISTER HEAD MACHINE SCREWS	2	NO. 5 - 40 NC-2
T	RELEASE PLUNGER	1	
U	PIN	1	
V	RELEASE THRUST COLLAR	1	
W	RELEASE LATCH	1	
X	PIN	1	
Y	PIN	1	
Z	RELEASE SPRINGS	2	
	THRUST COLLAR SET SCREWS	2	1/4 - 20 NC-2
	PLUNGER LOCK	1	
	PLUNGER LOCK SPRING	1	
AA	WATER JACKET NIPPLES	2	
BB	WATER JACKET	1	
CC	SOLENOID	1	PROVIDED
DD	BELL JAR		

ASSEMBLY

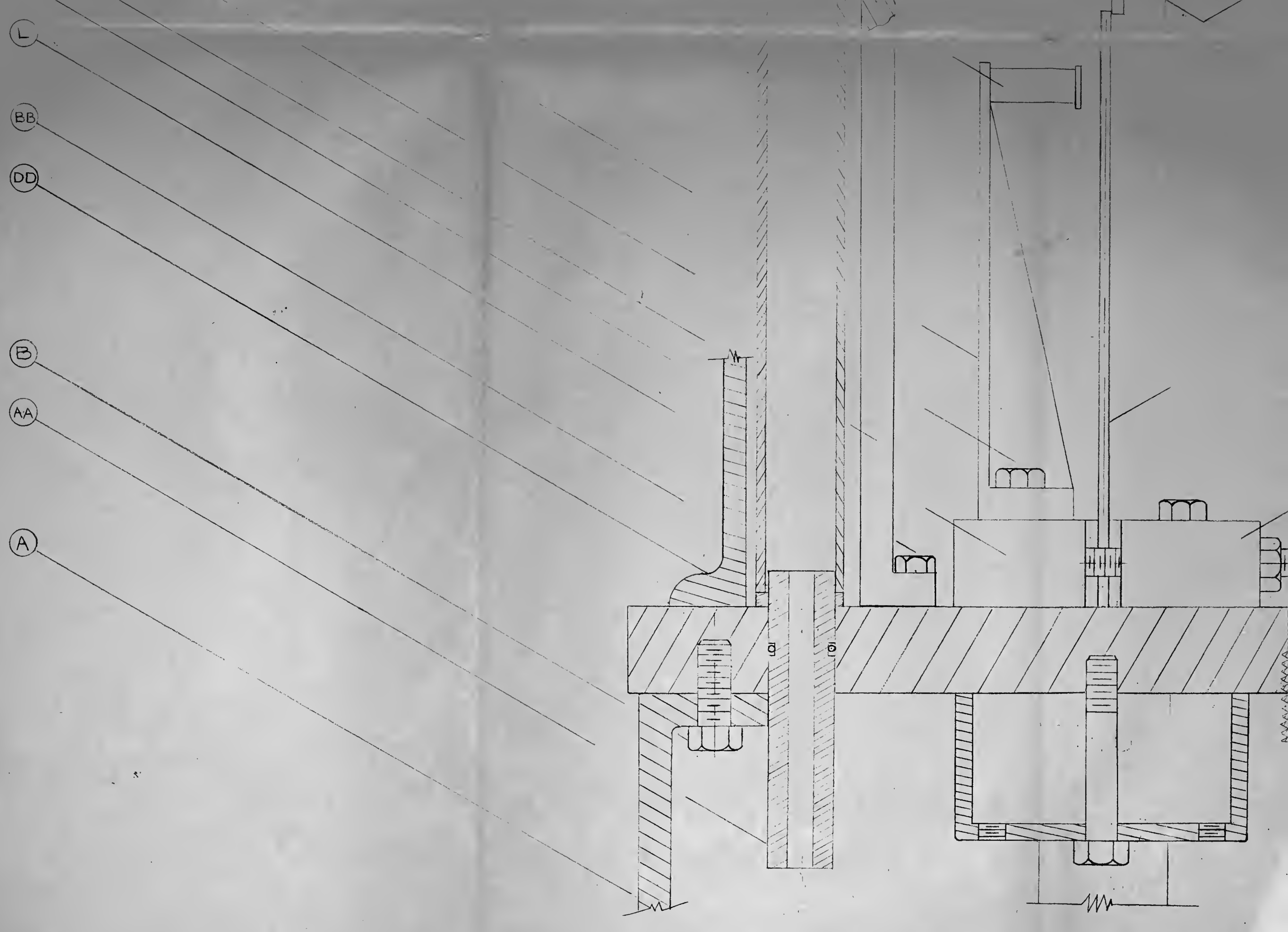
DAMPING CAPACITY TESTING MACHINE.

S. W. BACON.

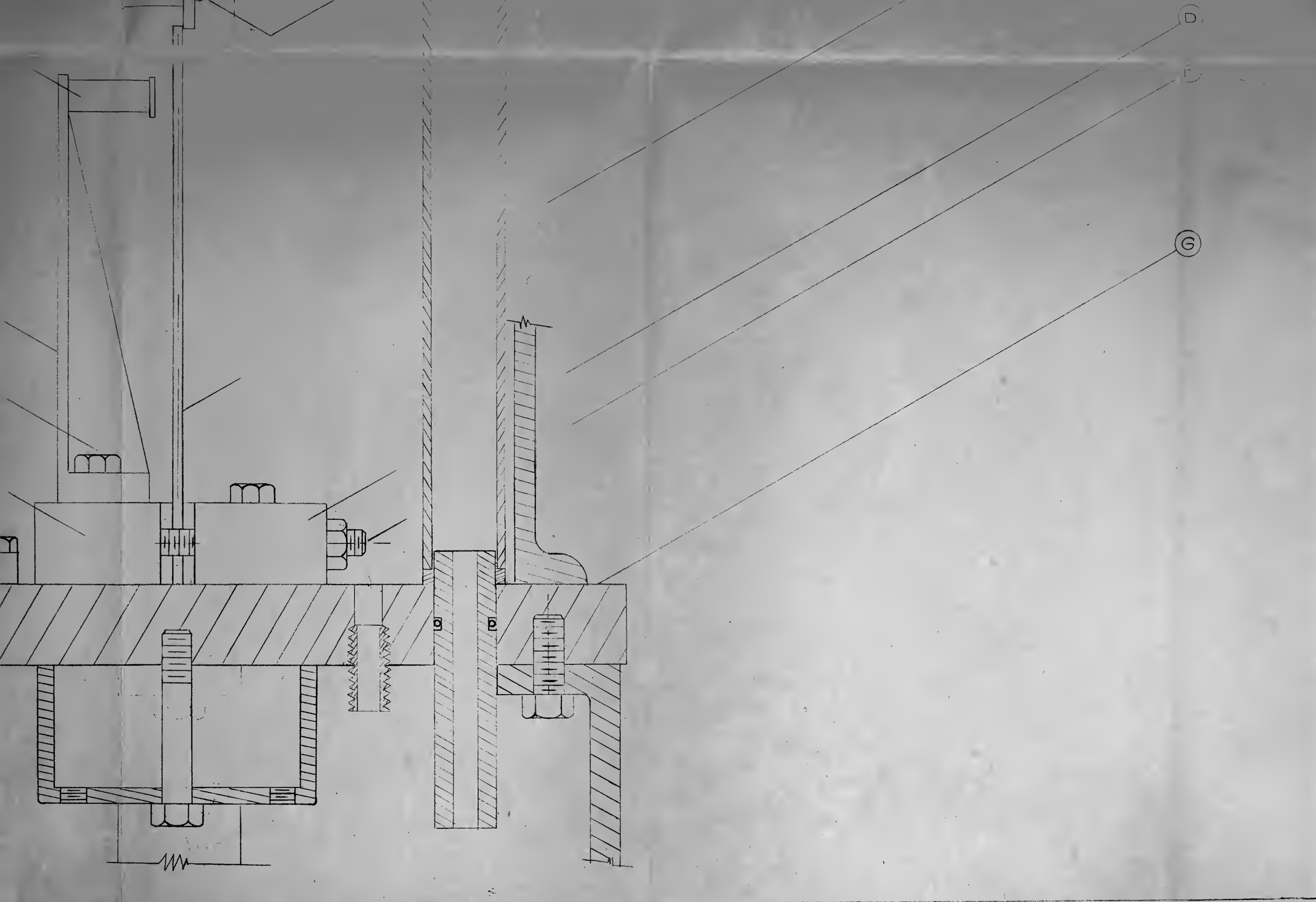

CC
Y
R
P
Q
N
O
I
H
E
K
C
L

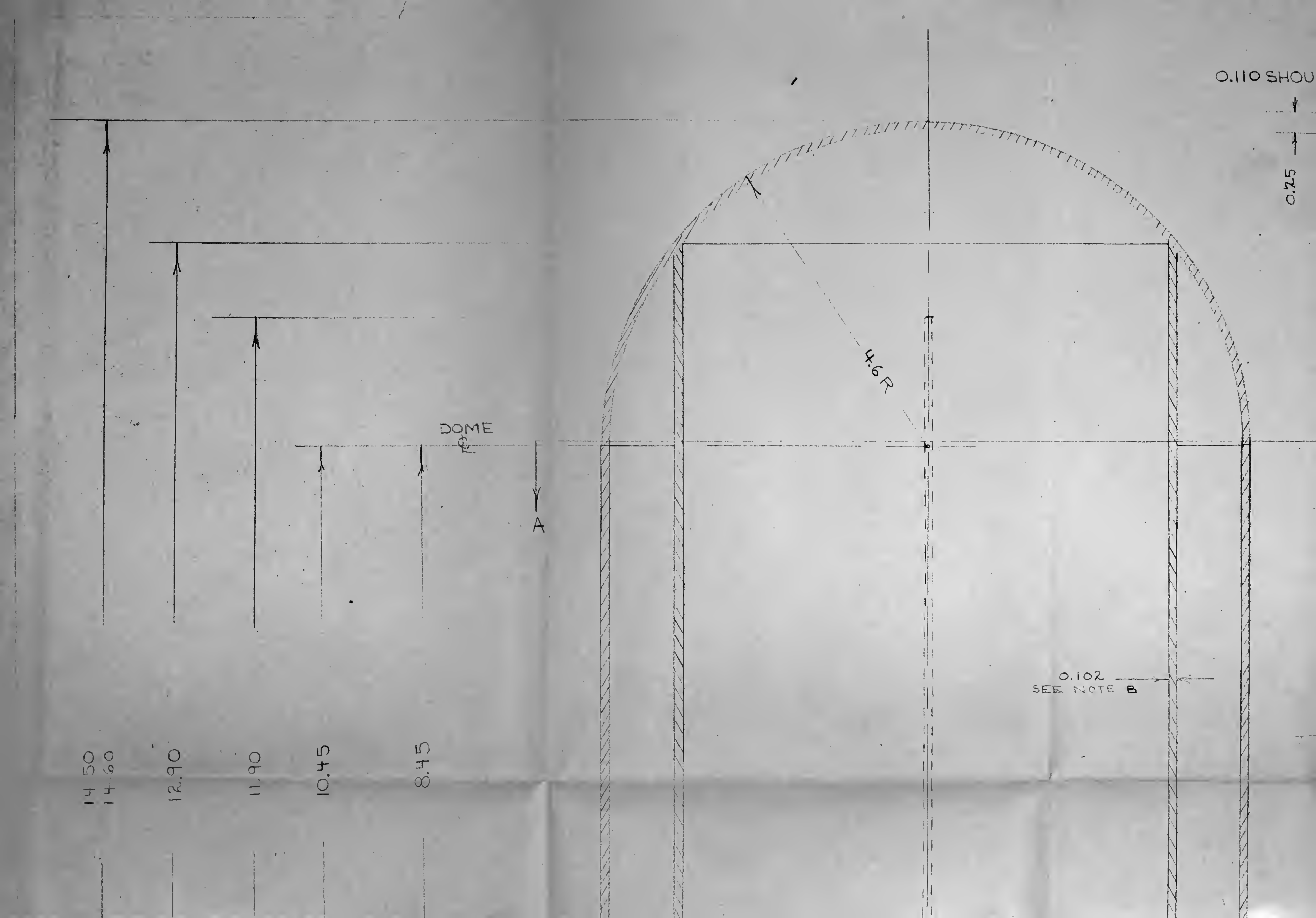


W
X
M
V
Z
U
S
J
D

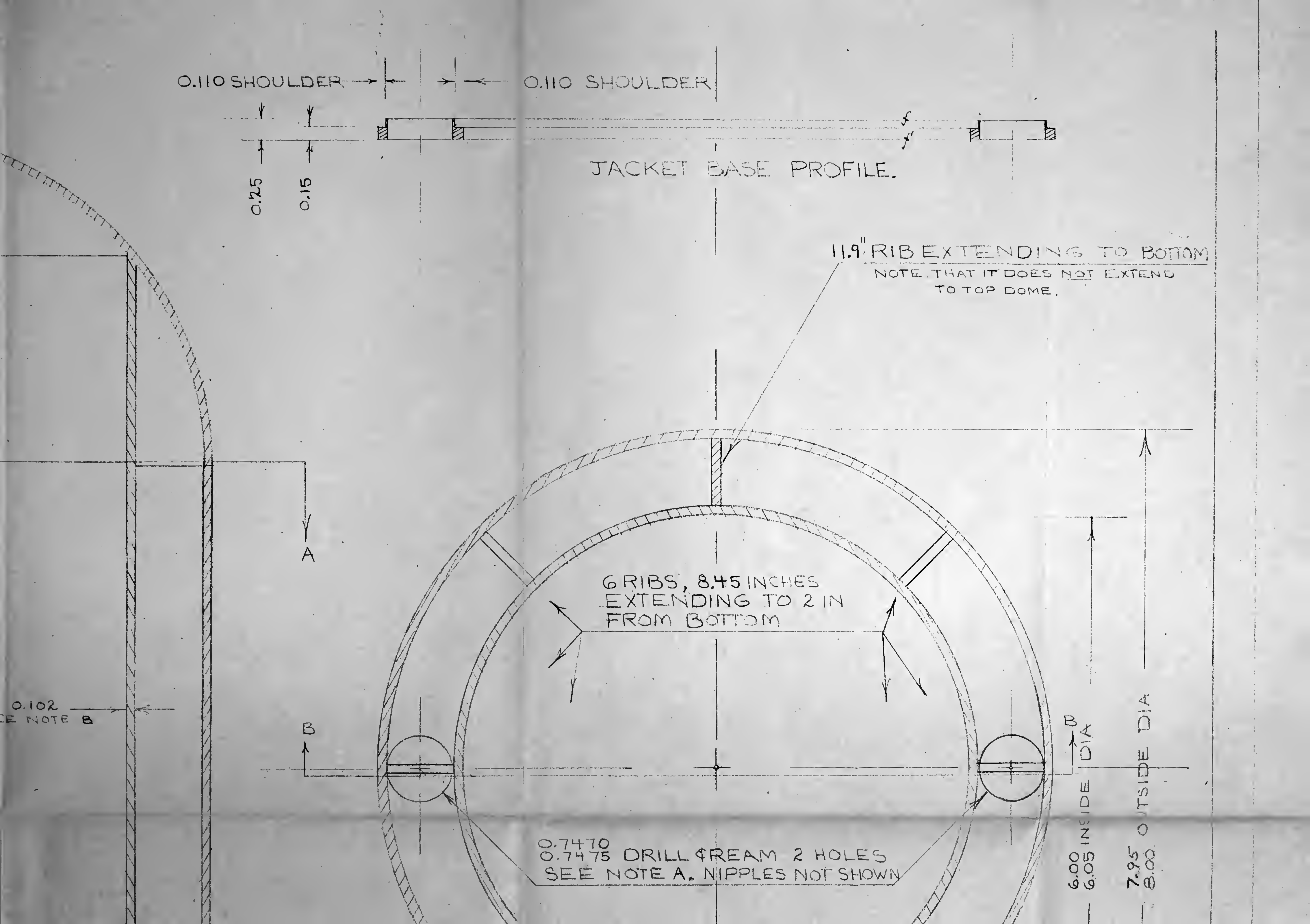


L
BB
DD
B
AA
A

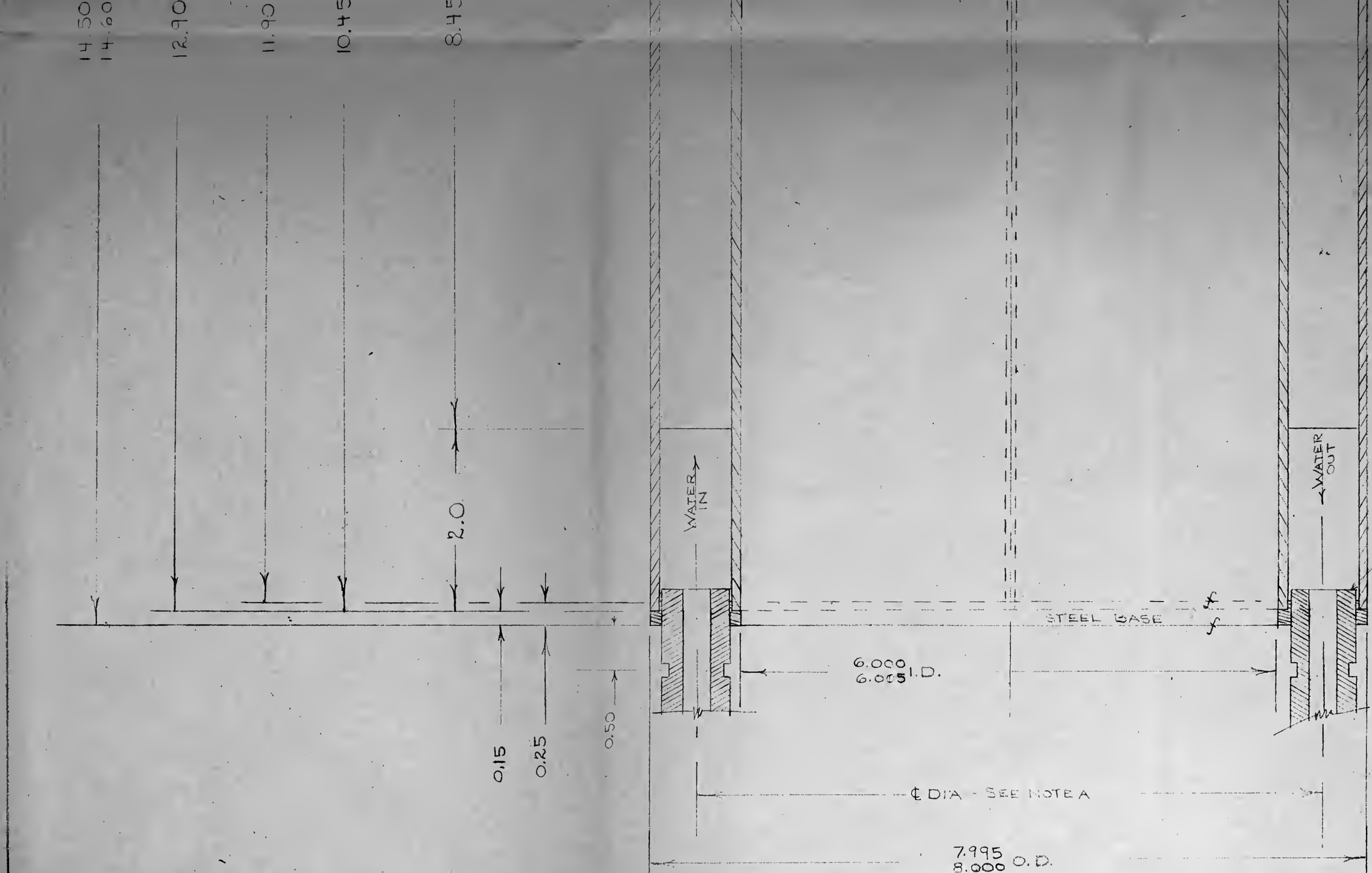

D
G



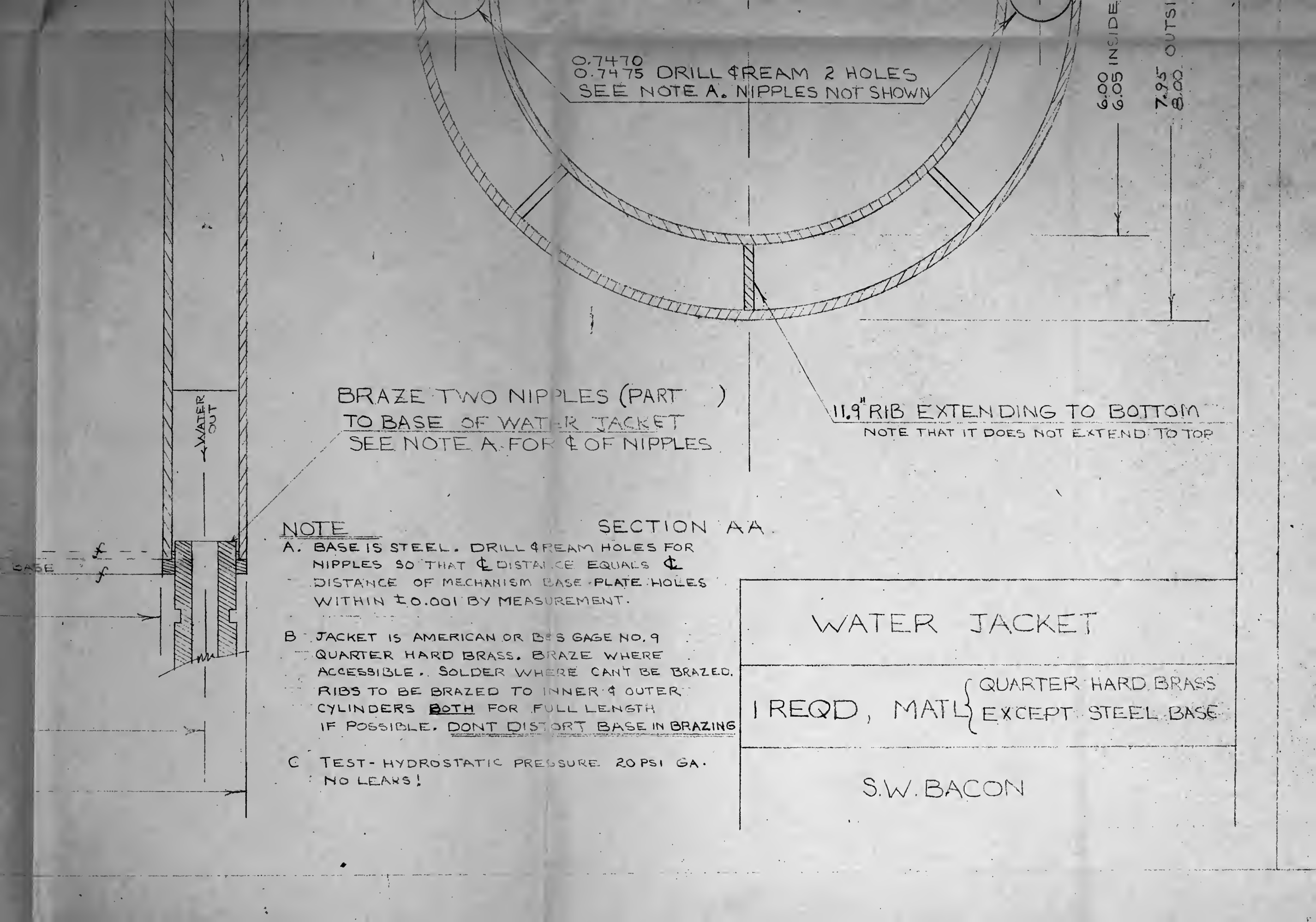
0.110 SHOU
0.25
4.6R
DOME ℄
A
0.102
SEE NOTE B
14.50
14.60
12.90
11.90
10.45
8.45

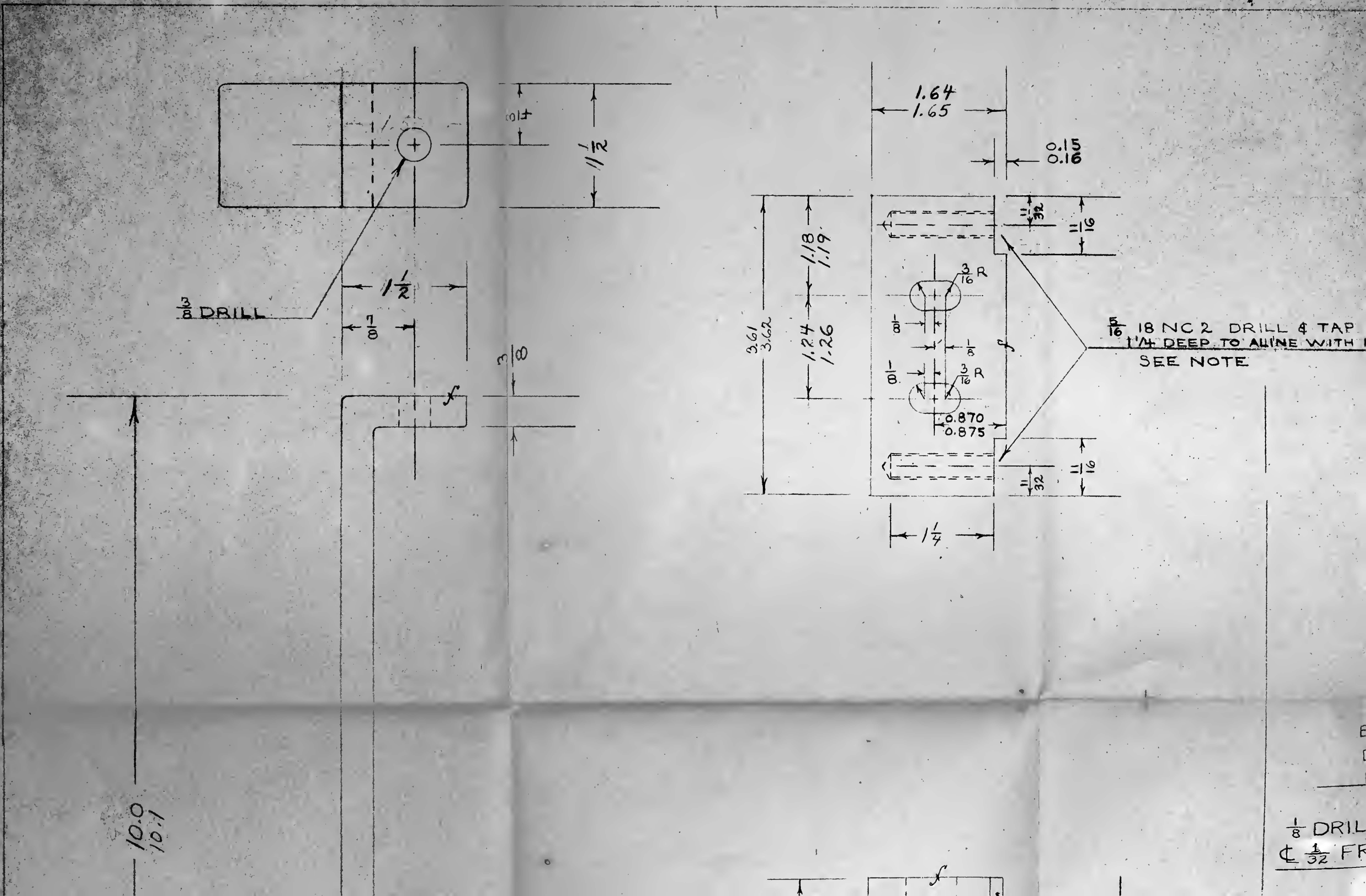


0.110 SHOULDER
0.110 SHOULDER
0.25
0.15
JACKET BASE PROFILE.
11.9" RIB EXTENDING TO BOTTOM
NOTE THAT IT DOES NOT EXTEND TO TOP DOME.
A
6 RIBS, 8.45 INCHES EXTENDING TO 2 IN FROM BOTTOM
0.102
E NOTE B
B
B
0.7470
0.7475 DRILL & REAM 2 HOLES
SEE NOTE A. NIPPLES NOT SHOWN
6.00
6.05 INSIDE DIA
7.95
8.00 OUTSIDE DIA

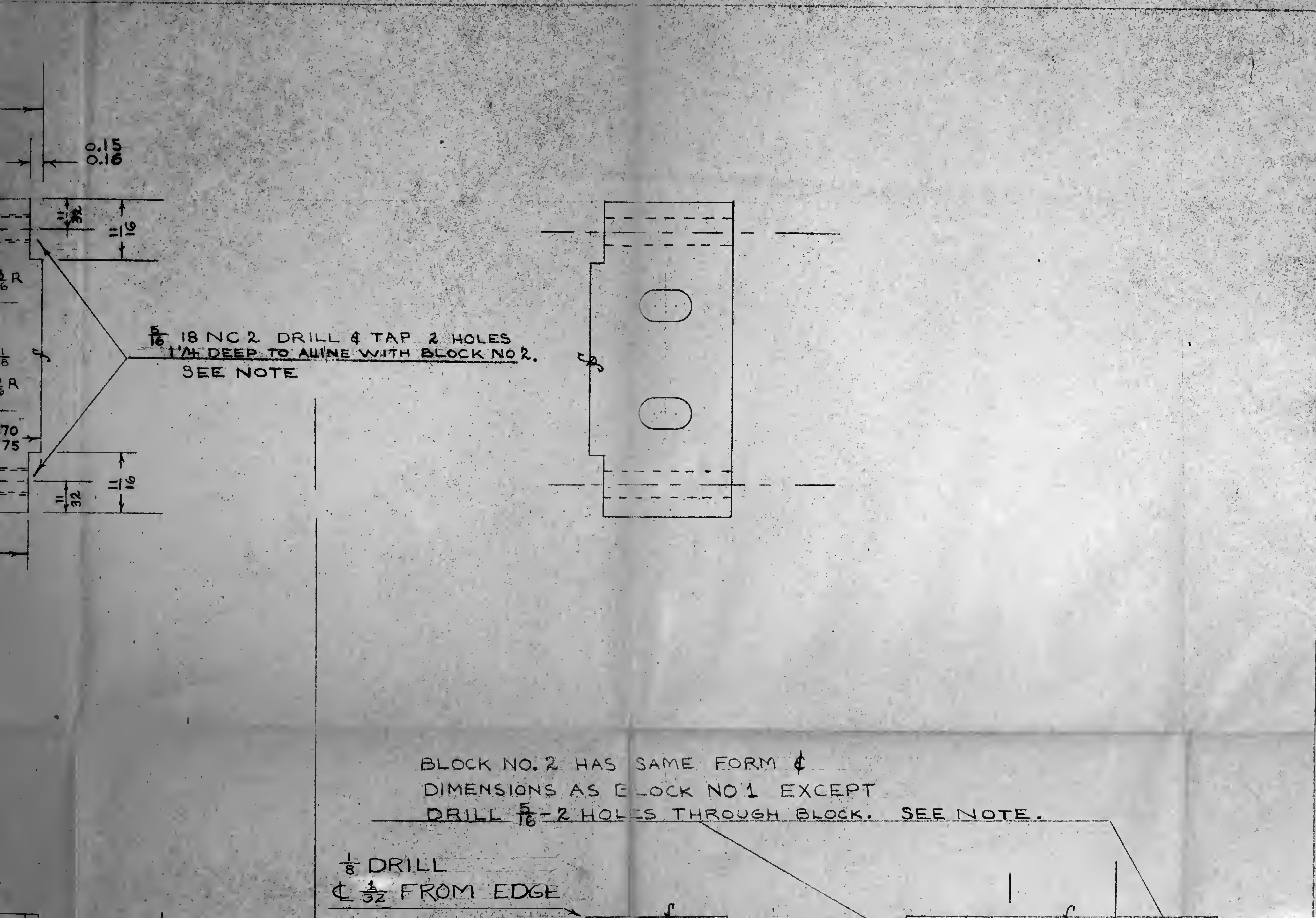

14.50
14.60
12.90
11.90
10.45
8.45
2.0
0.15
0.25
0.50
WATER IN
WATER OUT
STEEL BASE
6.000
6.005 I.D.
℄ DIA - SEE NOTE A
7.995
8.000 O.D.

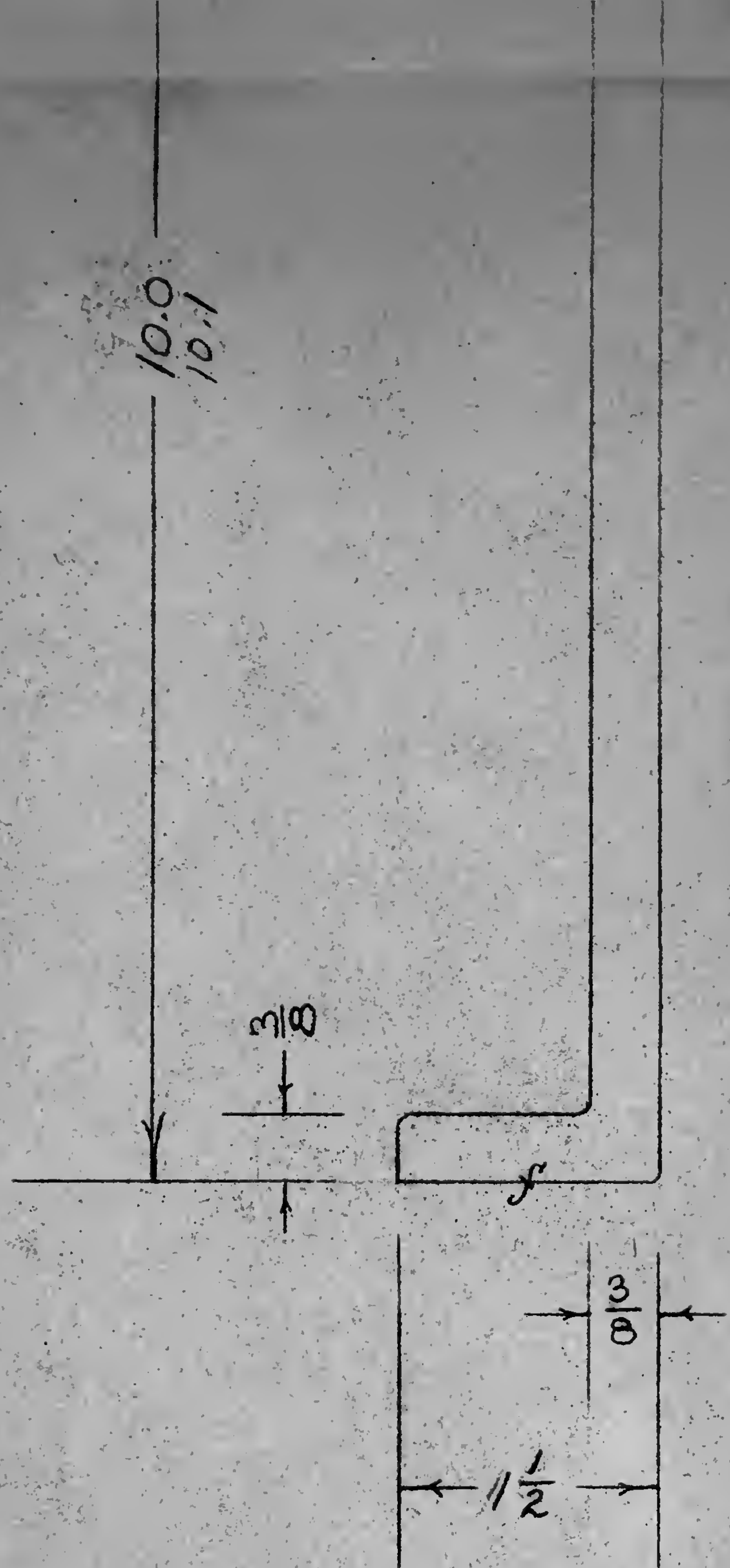
SECTION BB


0.7470
0.7475 DRILL & REAM 2 HOLES
SEE NOTE A. NIPPLES NOT SHOWN
6.00
6.05 INSIDE
7.95
8.00 OUTSI
WATER OUT
BASE
BRAZE TWO NIPPLES (PART)
TO BASE OF WATER JACKET
SEE NOTE A FOR ℄ OF NIPPLES
11.9" RIB EXTENDING TO BOTTOM
NOTE THAT IT DOES NOT EXTEND TO TOP
NOTE
SECTION AA
A. BASE IS STEEL. DRILL & REAM HOLES FOR NIPPLES SO THAT ℄ DISTANCE EQUALS ℄ DISTANCE OF MECHANISM BASE PLATE HOLES WITHIN ±0.001 BY MEASUREMENT.
B JACKET IS AMERICAN OR B&S GAGE NO. 9 QUARTER HARD BRASS. BRAZE WHERE ACCESSIBLE. SOLDER WHERE CAN'T BE BRAZED. RIBS TO BE BRAZED TO INNER & OUTER CYLINDERS BOTH FOR FULL LENGTH IF POSSIBLE. DONT DISTORT BASE IN BRAZING
C TEST - HYDROSTATIC PRESSURE 20 PSI GA. NO LEAKS!
WATER JACKET
1 REQD, MATL QUARTER HARD BRASS EXCEPT STEEL BASE
S.W. BACON

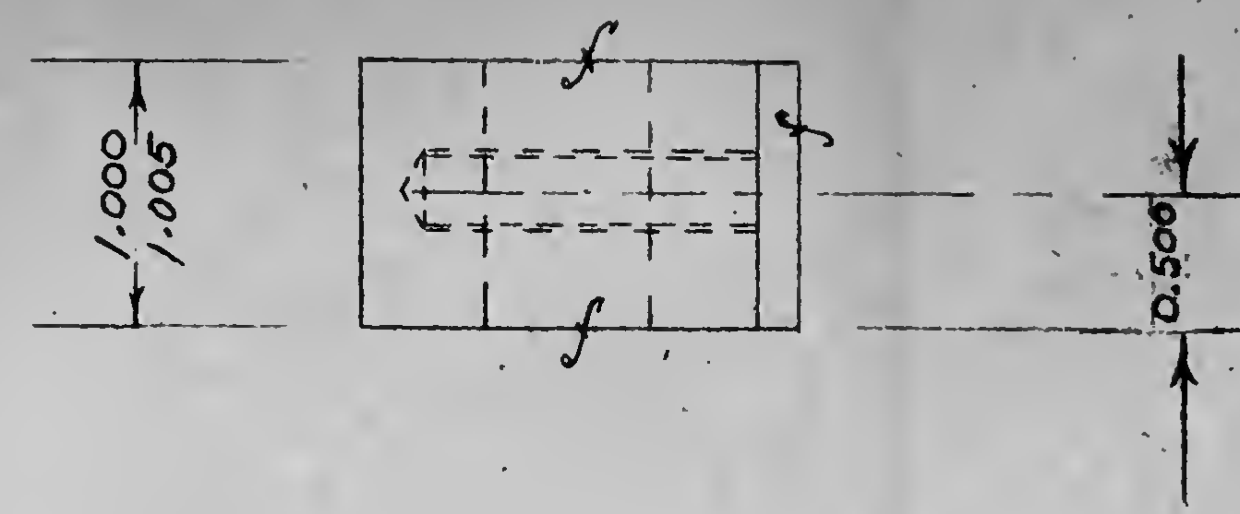


3/8 DRILL
1 1/2
7/8
3/8
1/4
1 1/2
10.0
10.1
1.64
1.65
0.15
0.16
1.18
1.19
3.61
3.62
1.24
1.26
3/16 R
1/8
0.870
0.875
11/32
11/16
1 1/4
5/16 18 NC 2 DRILL & TAP
1 1/4 DEEP TO ALINE WITH
SEE NOTE
1/8 DRIL
℄ 1/32 FR

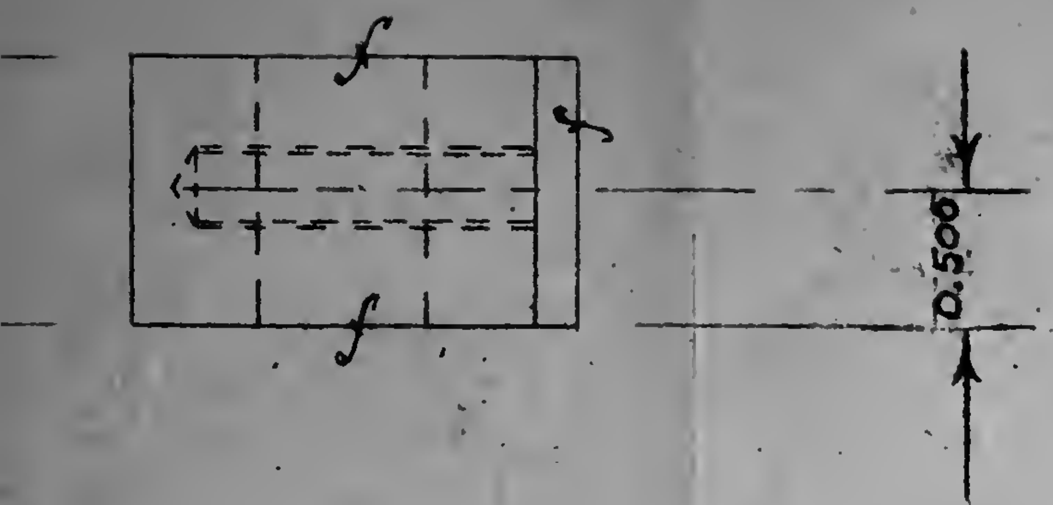

0.15
0.16
11/32
11/16
5/16 18 NC 2 DRILL & TAP 2 HOLES
1 1/4 DEEP TO ALINE WITH BLOCK NO 2.
SEE NOTE
.670
.675
11/16
11/32
BLOCK NO. 2 HAS SAME FORM &
DIMENSIONS AS BLOCK NO 1 EXCEPT
DRILL 5/16 - 2 HOLES THROUGH BLOCK. SEE NOTE.
1/8 DRILL
℄ 1/32 FROM EDGE



BASE PLATE LEGS
4 REQUIRED
HOT ROLLED STEEL



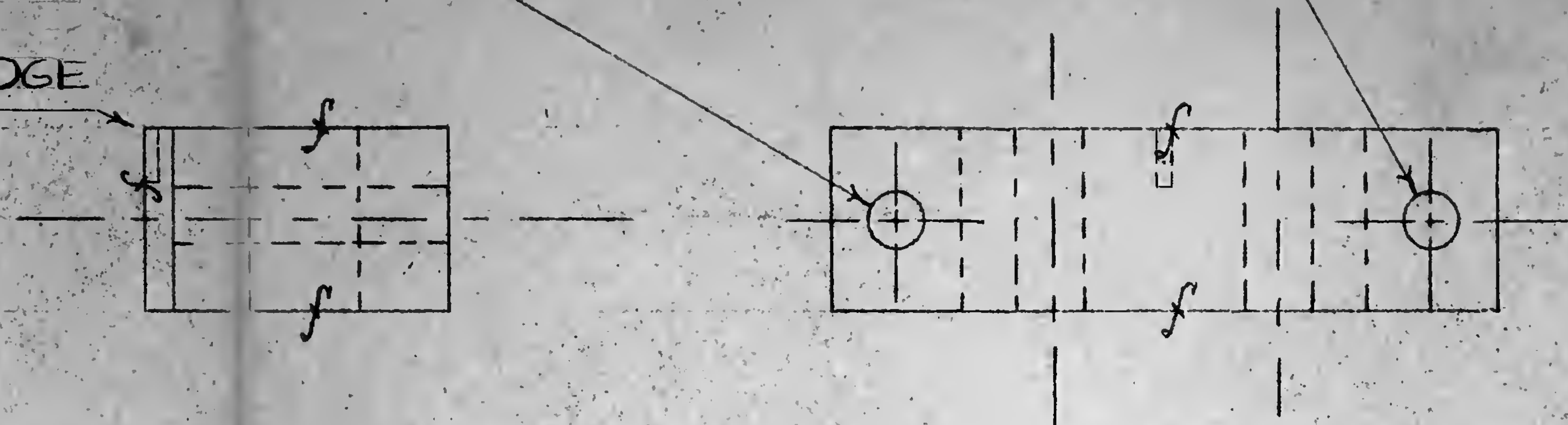
SAMPLE SUPPORT BLOCK NO. 1
1 REQD. HOT ROLLED STEEL



SAMPLE SUPPORT BLOCK NO. 1
1 REQD. HOT ROLLED STEEL

BLOCK NO. 2 HAS SAME FORM &
DIMENSIONS AS BLOCK NO 1 EXCEPT
DRILL $\frac{5}{16}$ - 2 HOLES THROUGH BLOCK. SEE NOTE.

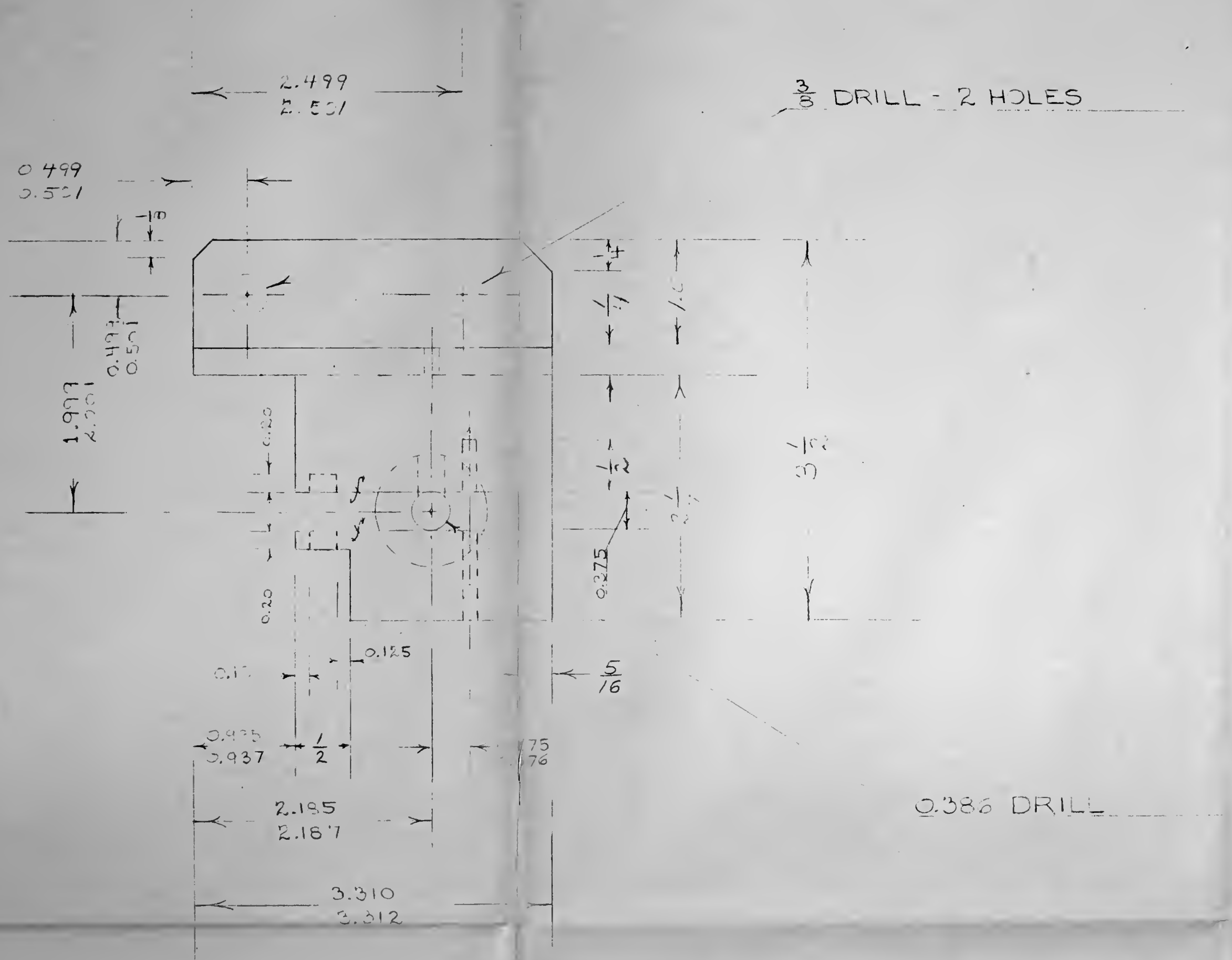
$\frac{1}{8}$ DRILL
℄ $\frac{1}{32}$ FROM EDGE



SAMPLE SUPPORT BLOCK NO 2.
1 REQD. HOT ROLLED STEEL

NOTE. BLOCKS NO 1 & 2 TO BE JOINED BY 2 - $\frac{5}{16}$ INCH STUDS. STUDS TO PROVIDE FOR BLOCK SEPARATION FROM 0 TO $\frac{1}{2}$ INCH. PROVIDE STUDS & NUTS. NO DETAIL DWG OF STUDS WILL BE FURNISHED.

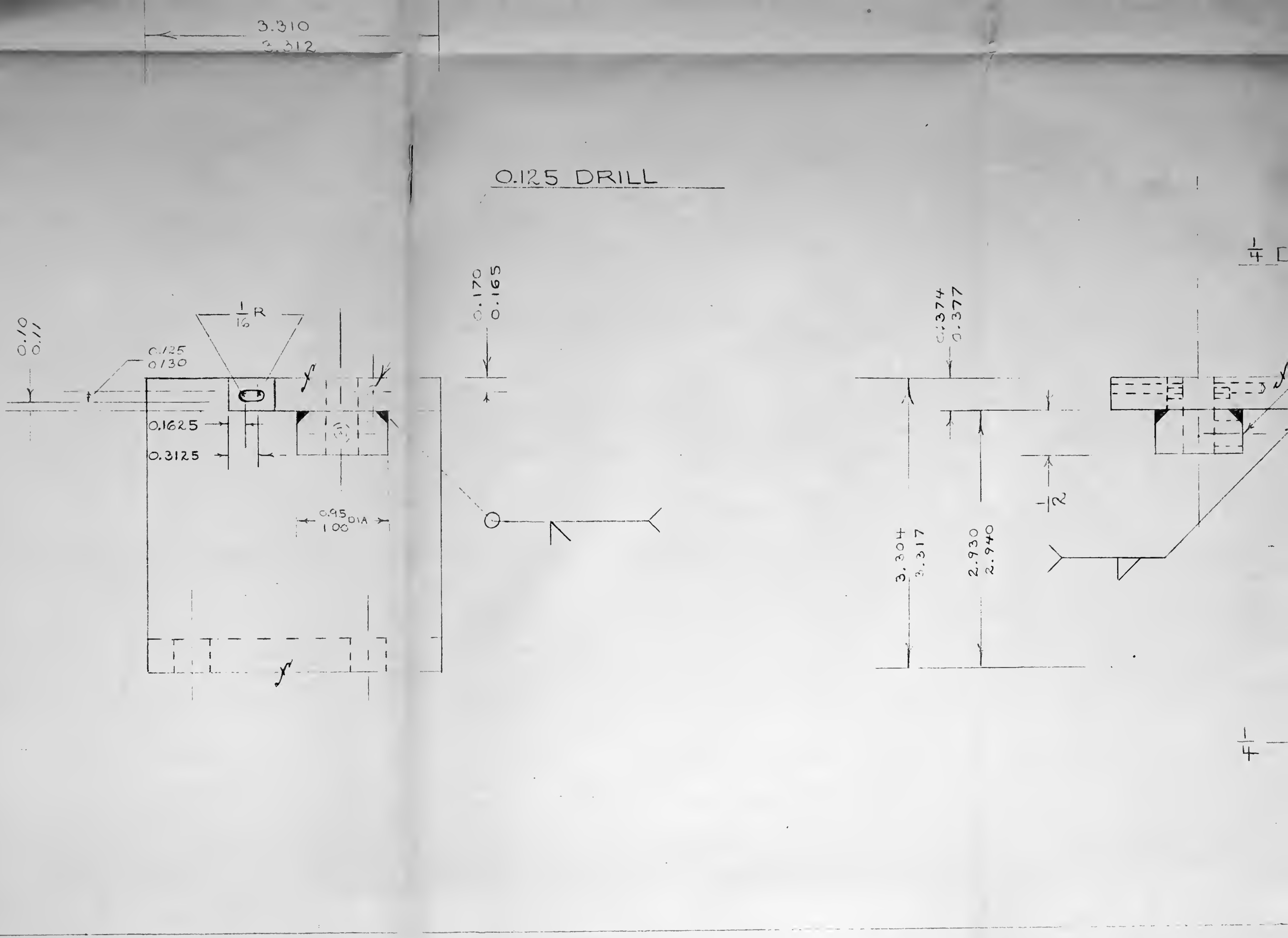
BASE PLATE LEGS & SAMPLE SUPPORT BLOCKS
HOT ROLLED STEEL 4 BASE PLATE LEGS REQUIRED 1 EACH - BLOCK NO. 1 & 2 REQUIRED
S.W. BACON



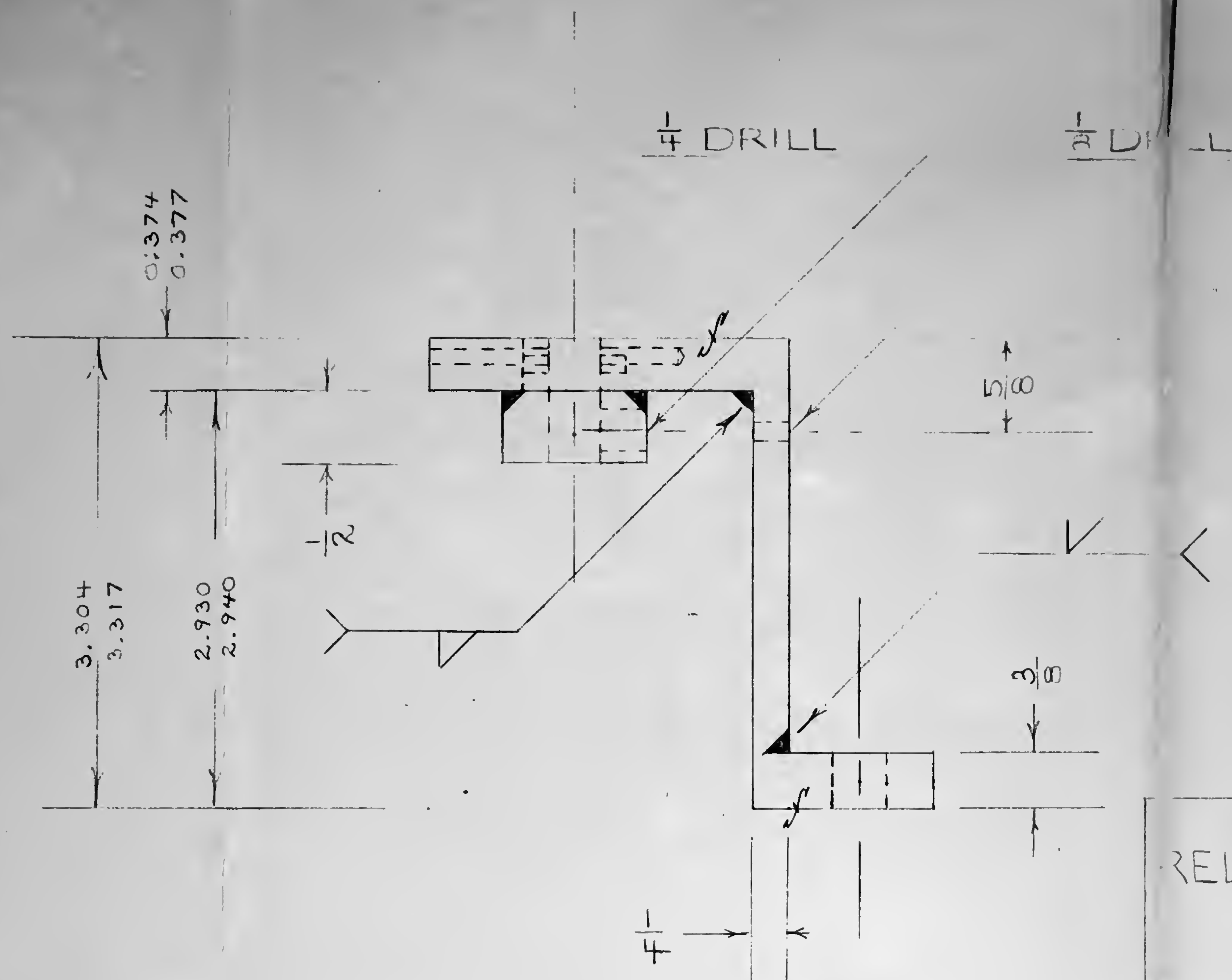
2.499
0.499
0.125
5/16
1/2
0.937
2.185
2.187
3.310
3.312
3/8 DRILL - 2 HOLES
0.386 DRILL

$\frac{3}{8}$ DRILL - 2 HOLES

0.386 DRILL



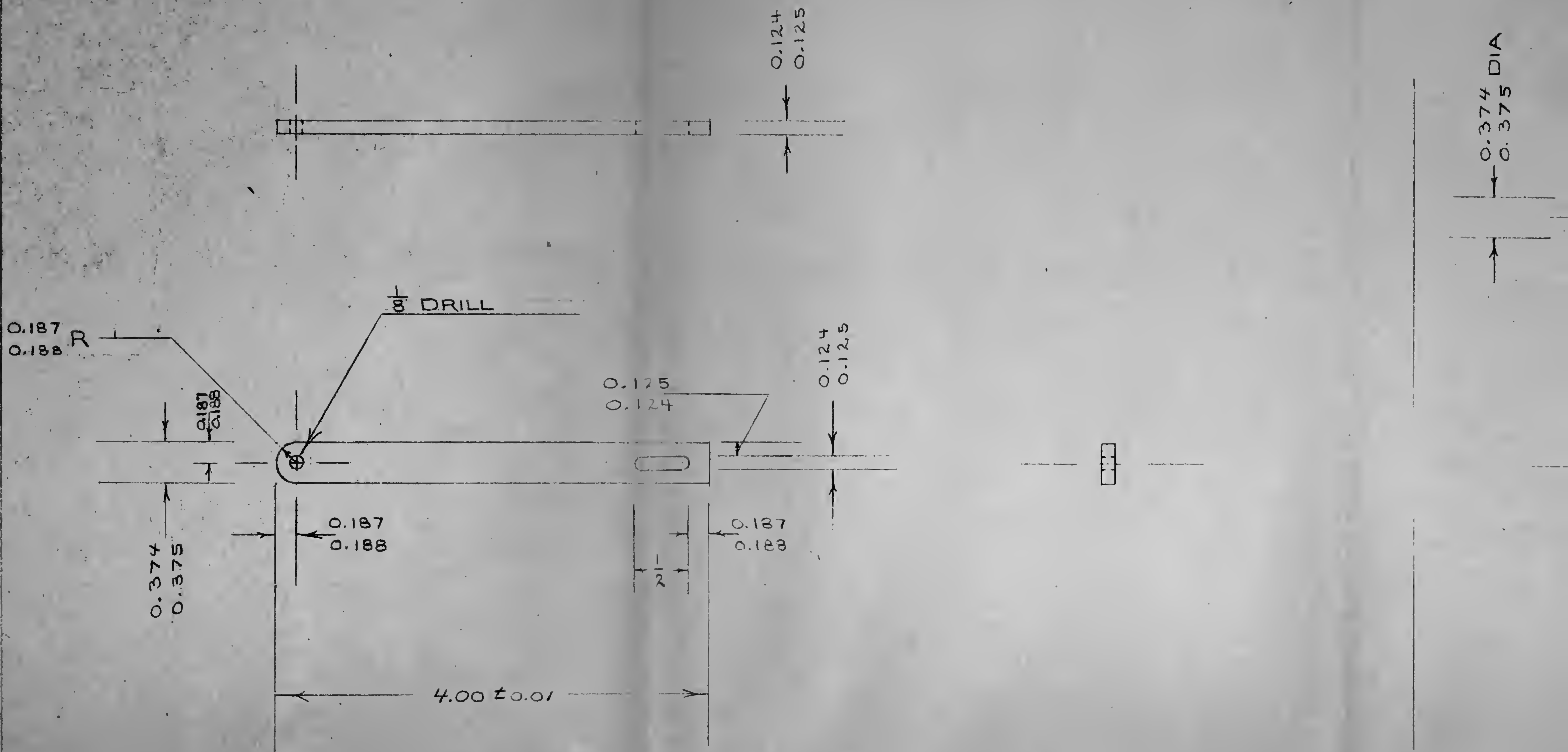
3.310
3.312
0.125 DRILL
0.10
0.11
0.125
0.130
1/16 R
0.1625
0.3125
0.170
0.165
0.95
1.00 DIA
0.374
0.377
3.304
3.317
2.930
2.940
1/2
1/4



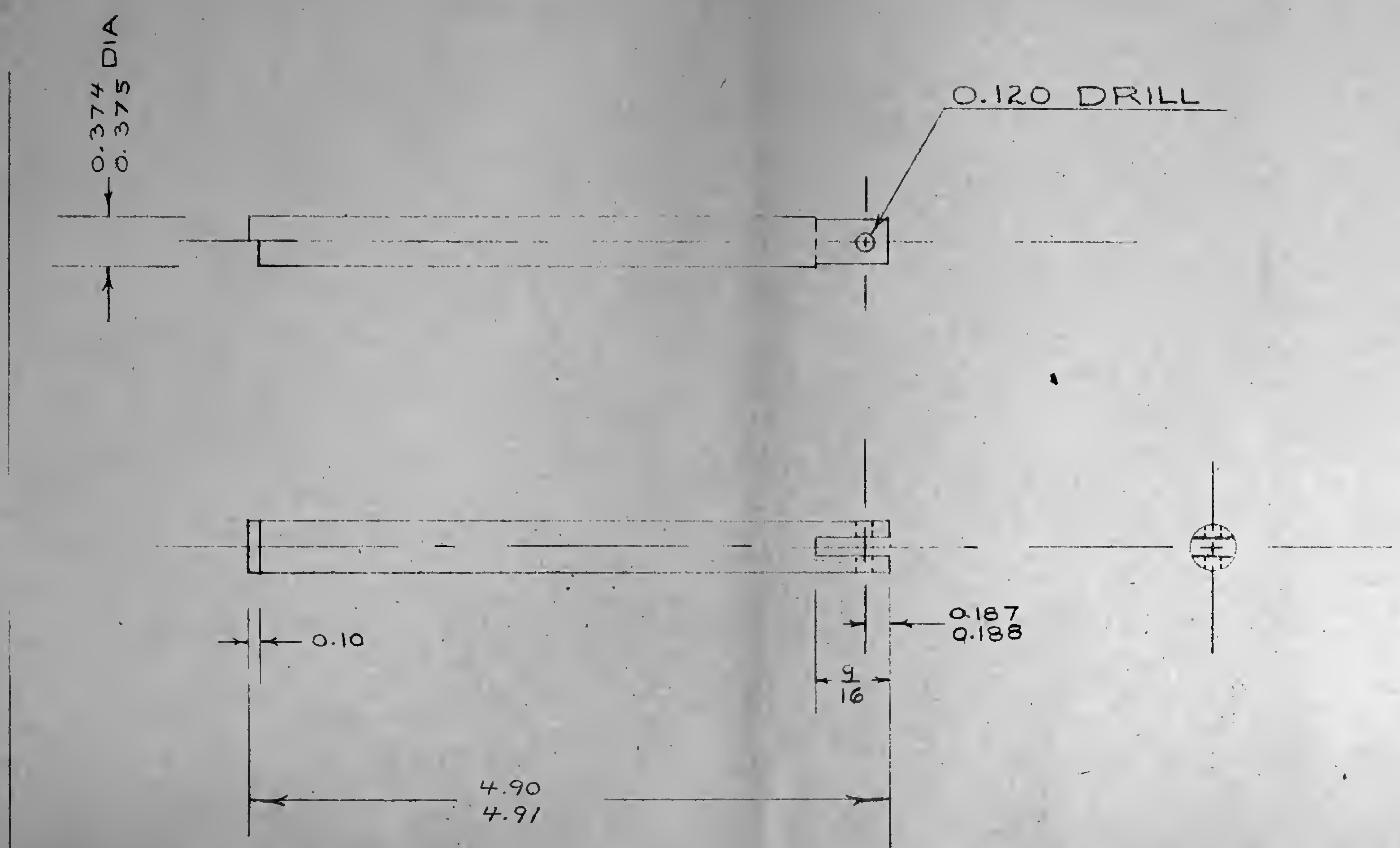
RELEASE MECHANISM BRACKET

MATL. HOT ROLLED STEEL
1 REQUIRED

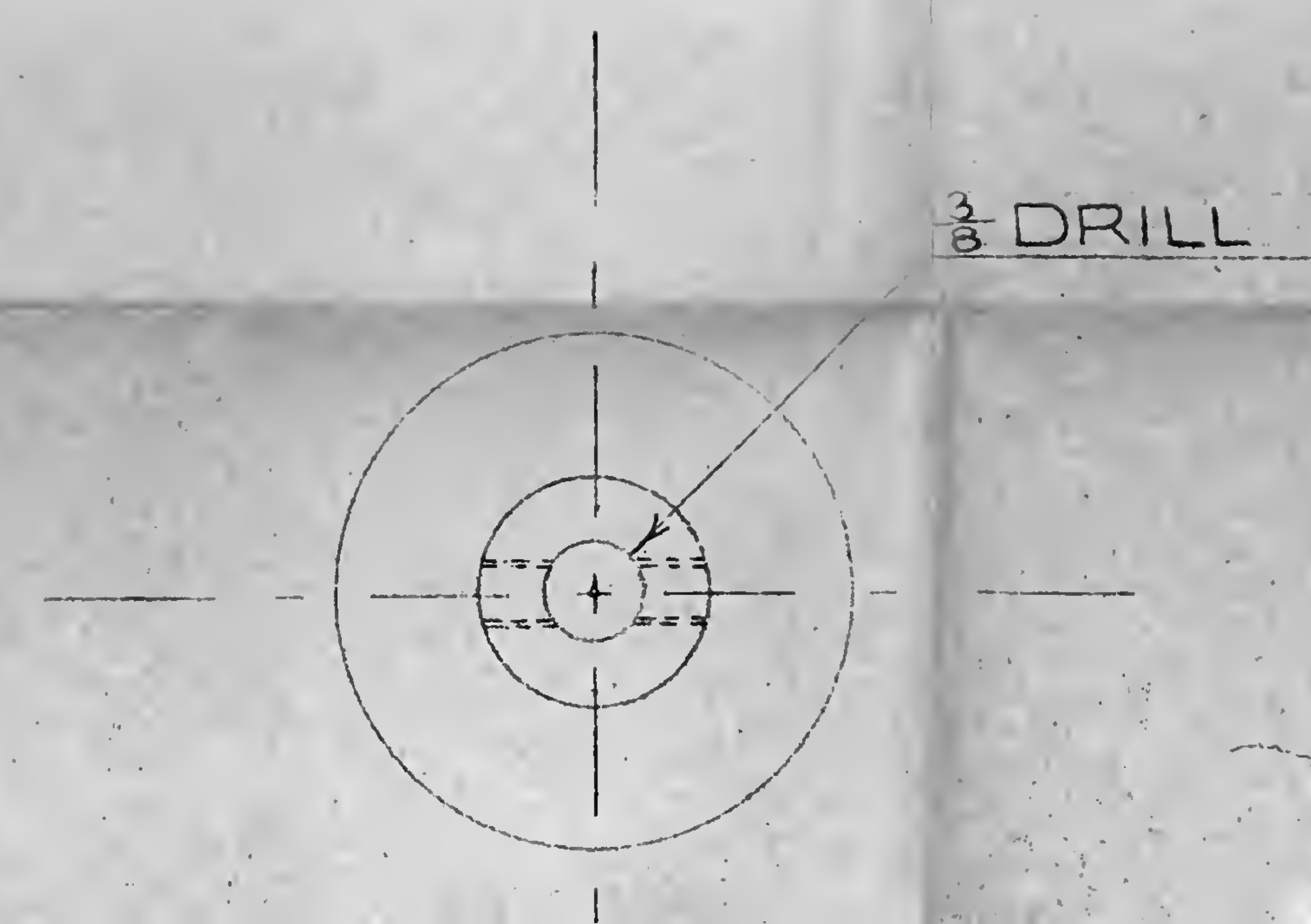
S.W. BACON



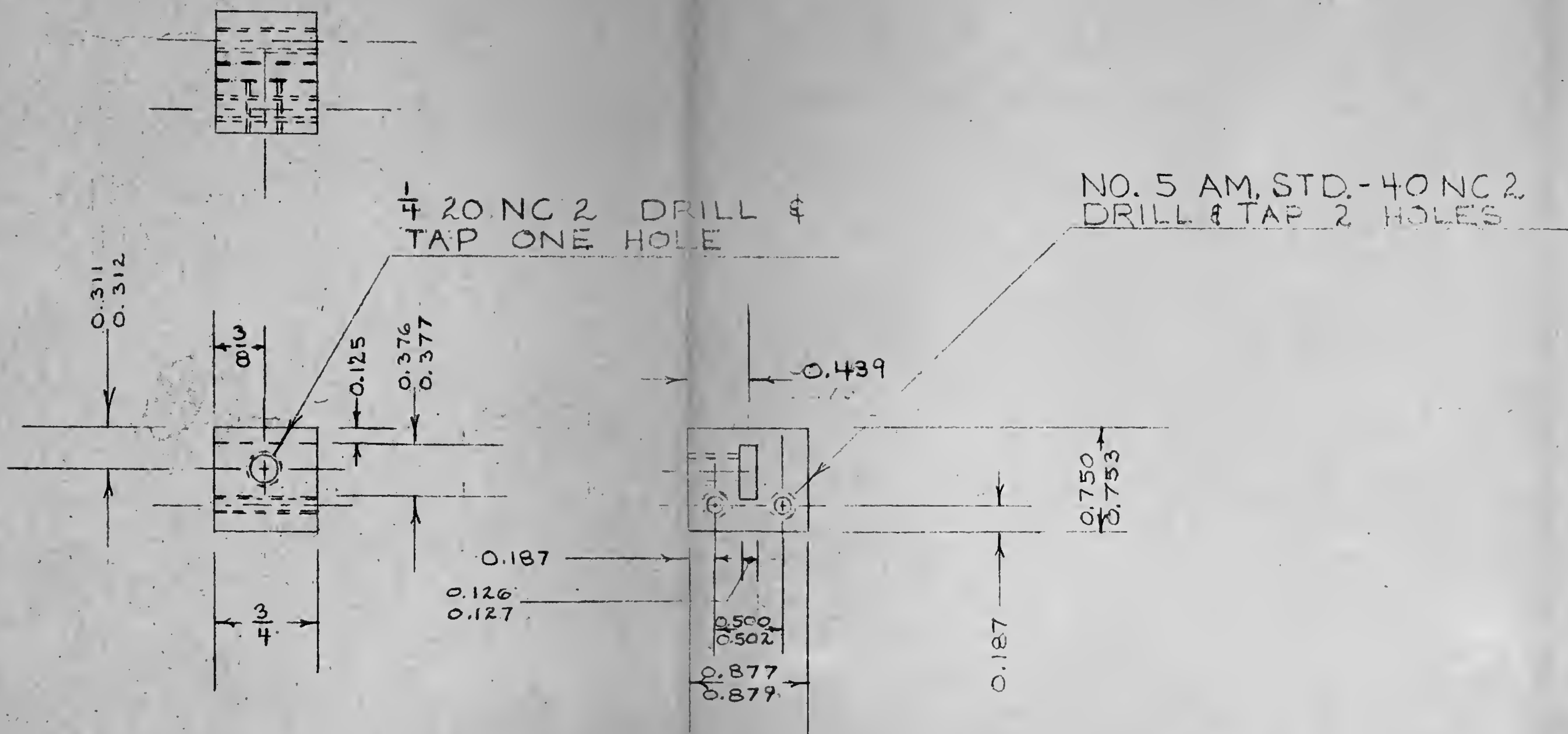
RELEASE LEVER



RELEASE PLUNGER

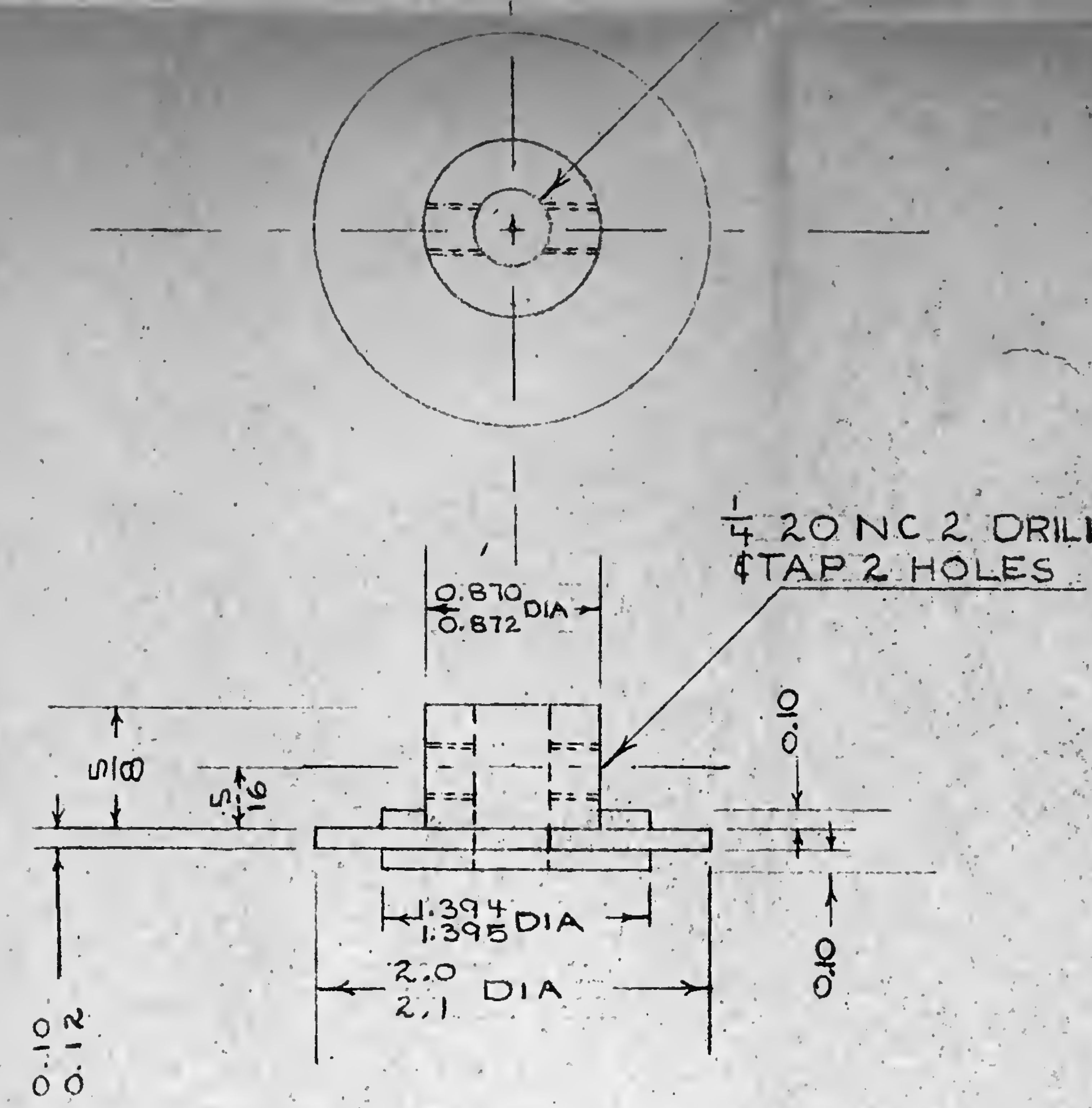


RELEASE LEVER

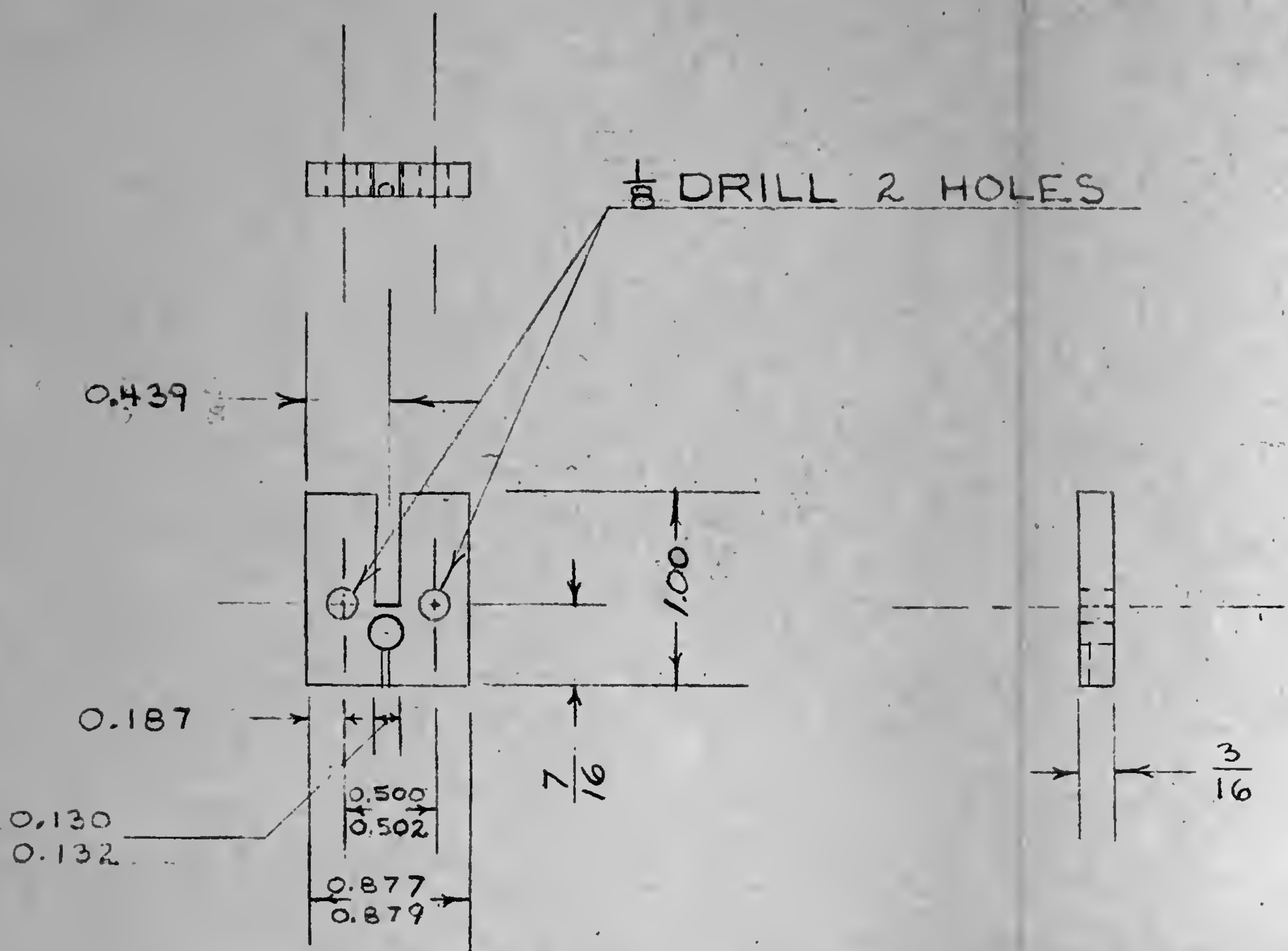


RELEASE ARM SUPPORT

RELEASE PLUNGER



RELEASE THRUST COLLAR

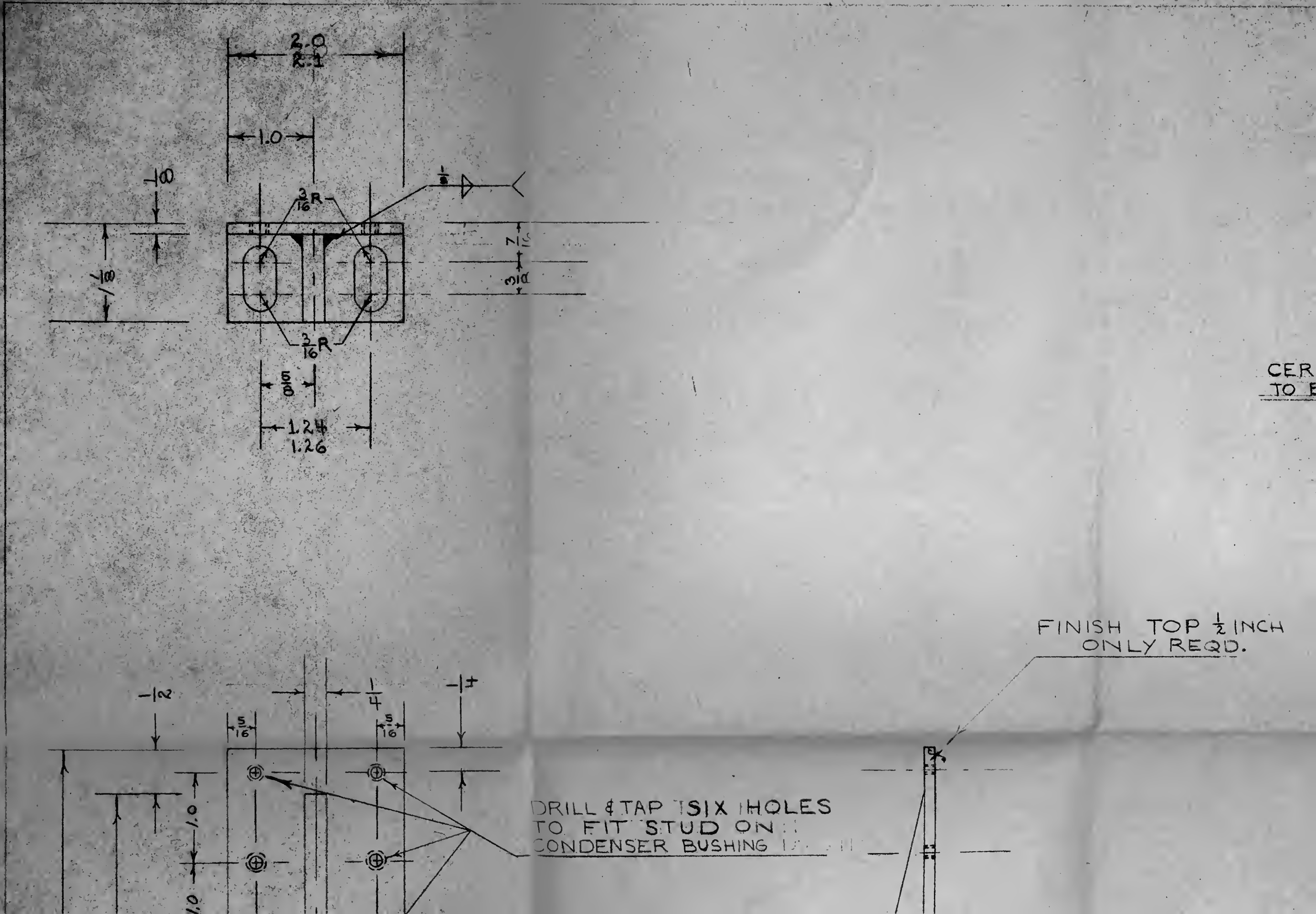


RELEASE ARM

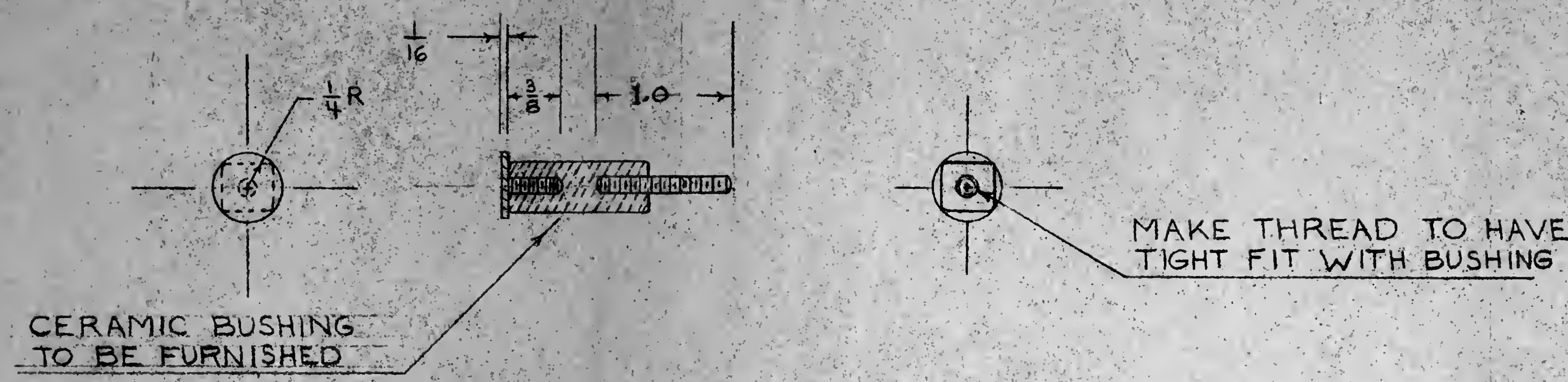
RELEASE MECHANISM DETAILS

MAT'L. HOT ROLLED STEEL
1 EACH REQUIRED
FINISHED ALL OVER

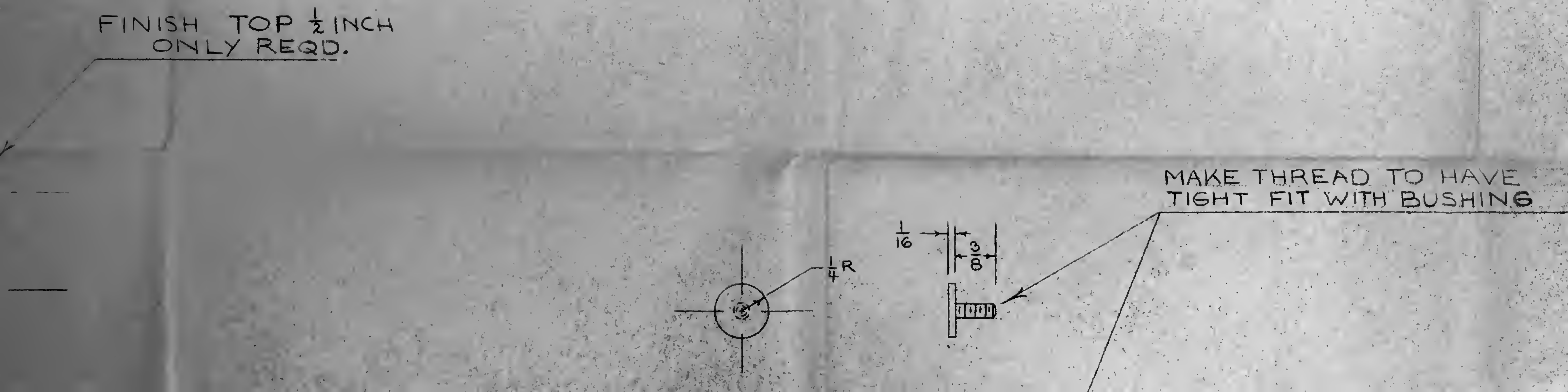
S.W. BACON

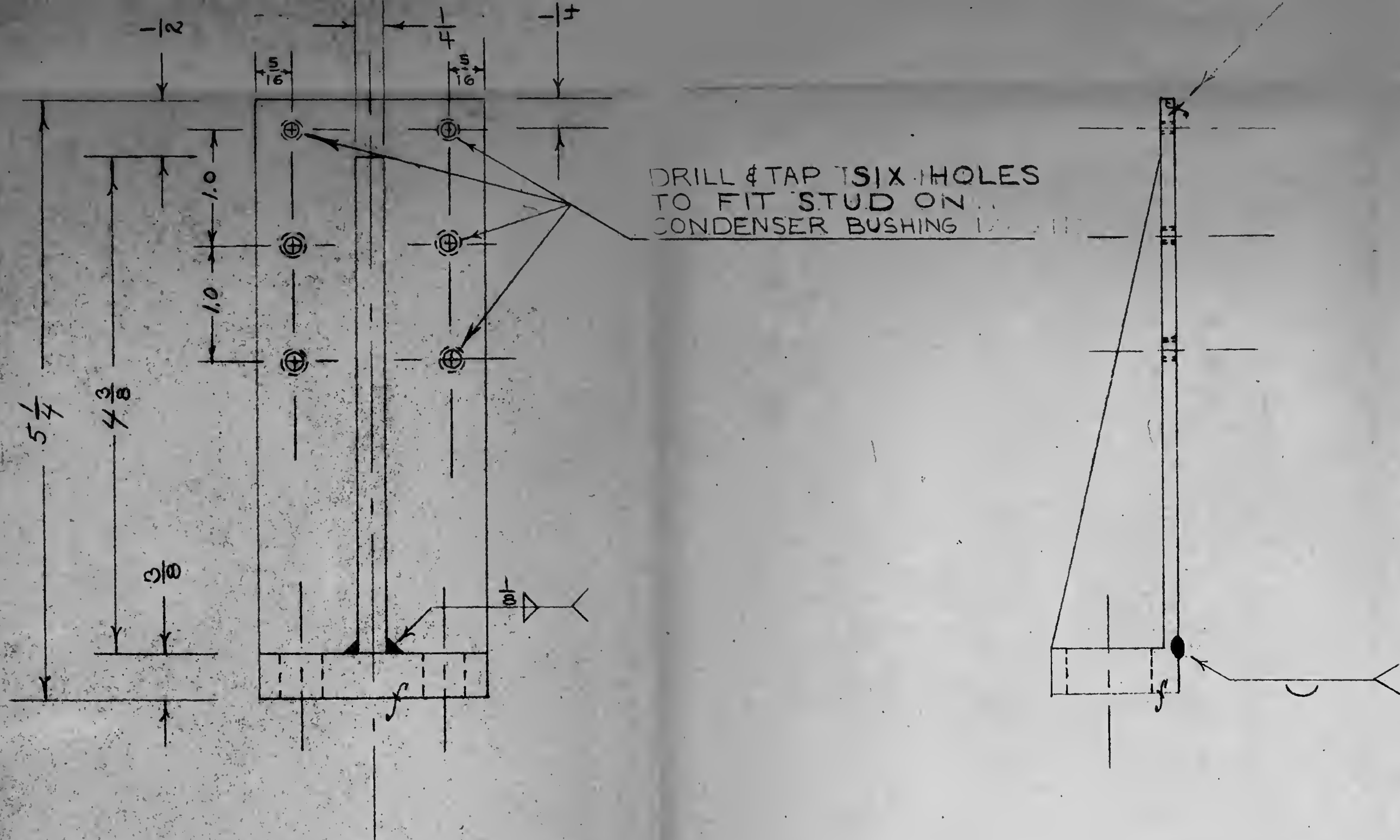


2.0
2.1
1.0
3/16 R
3/16 R
5/8
1.24
1.26
5/16
5/16
1/4
FINISH TOP ½ INCH
ONLY REQD.
DRILL & TAP SIX HOLES
TO FIT STUD ON
CONDENSER BUSHING



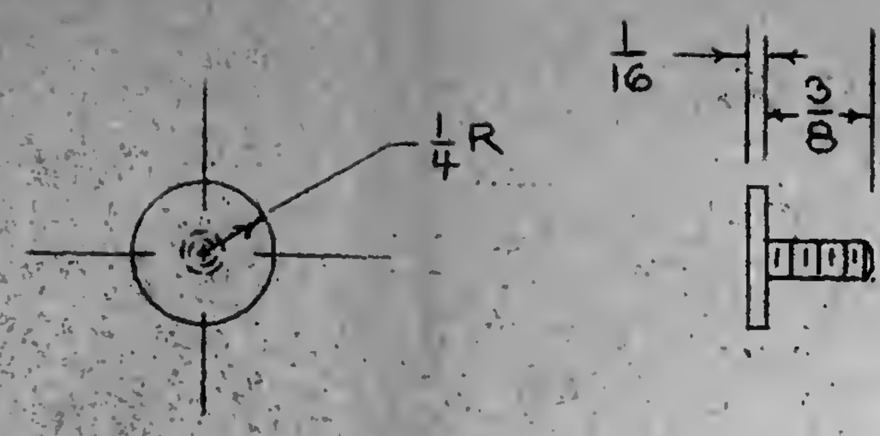
CONDENSER & CONDENSER BUSHING ASSEMBLED



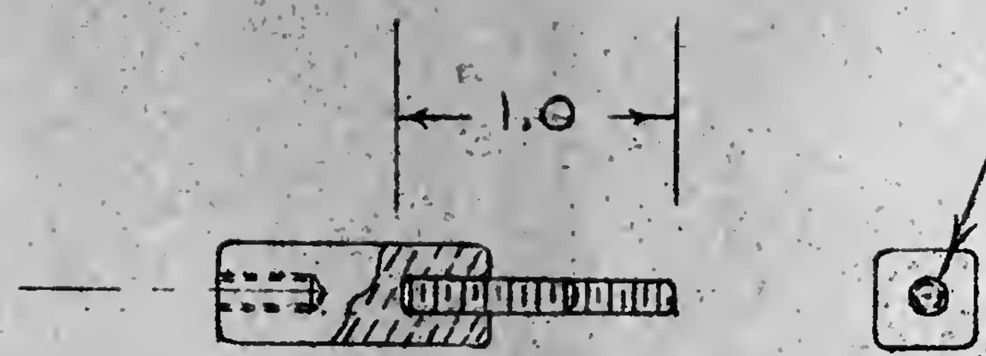


CONDENSER BRACKET

MAKE THREAD TO HAVE
TIGHT FIT WITH BUSHING



CONDENSER



CONDENSER BUSHING

CONDENSER BRACKET,
CONDENSER &
CONDENSER BUSHING

BRACKET - 1 REQD - MATL HOT ROLLED STL
CONDENSER - 2 REQD - STEEL OR BRASS
CONDENSER BUSHING - 2 REQD - MATL
CERAMIC WITH STEEL STUD

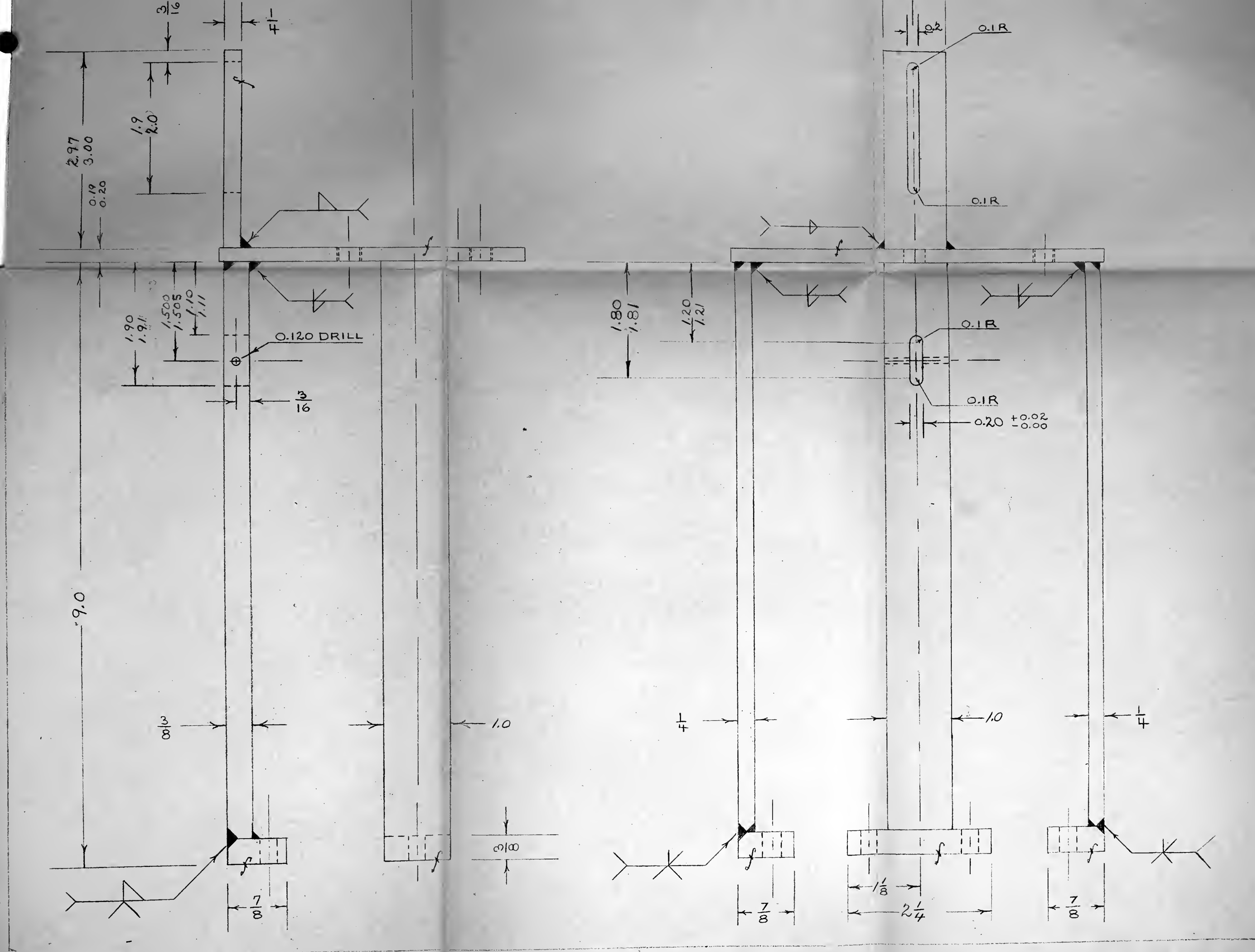
S.W. BACON

RELEASE MECHANISM BASE

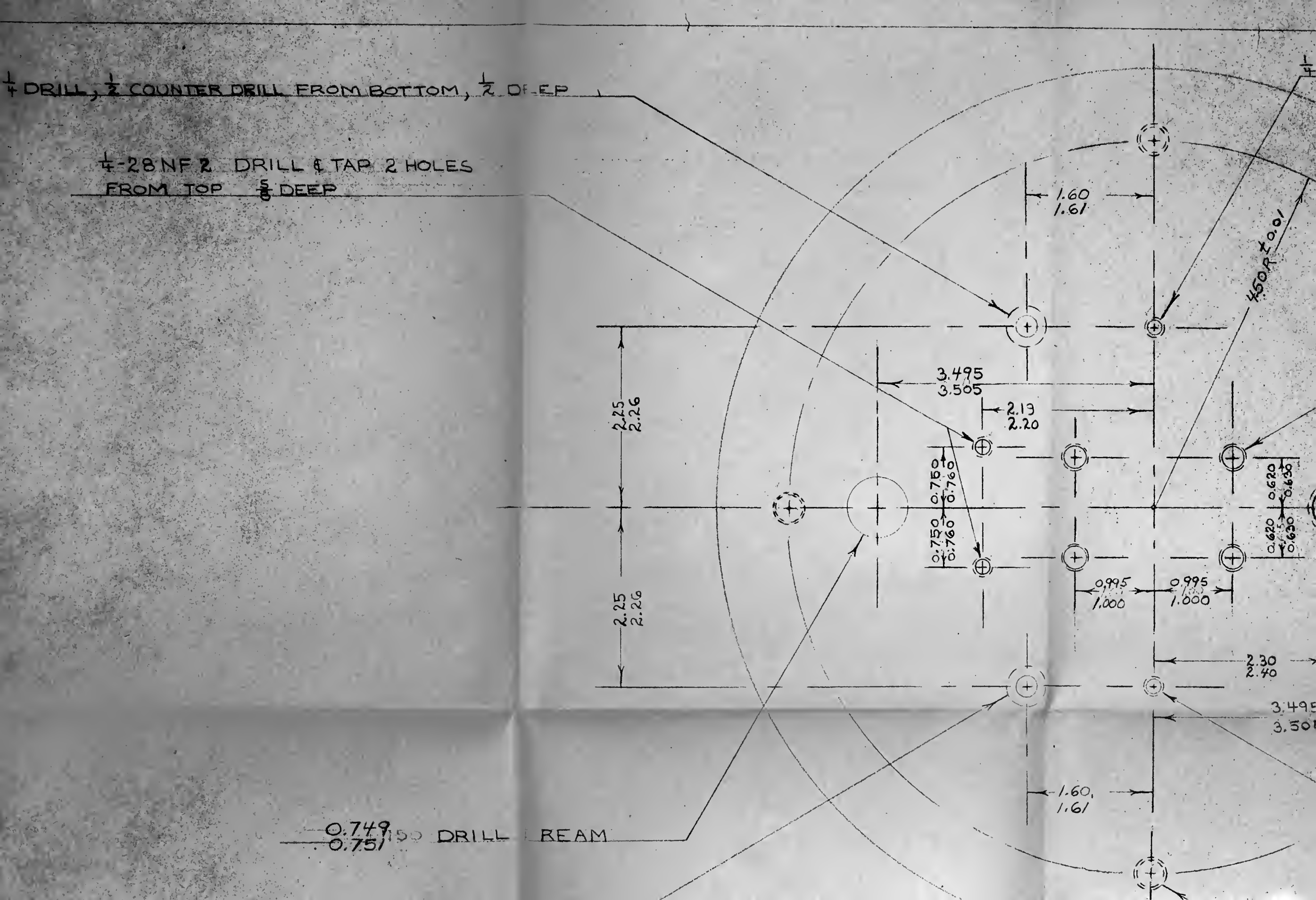
MATL: HOT ROLLED STEEL

1 REQUIRED

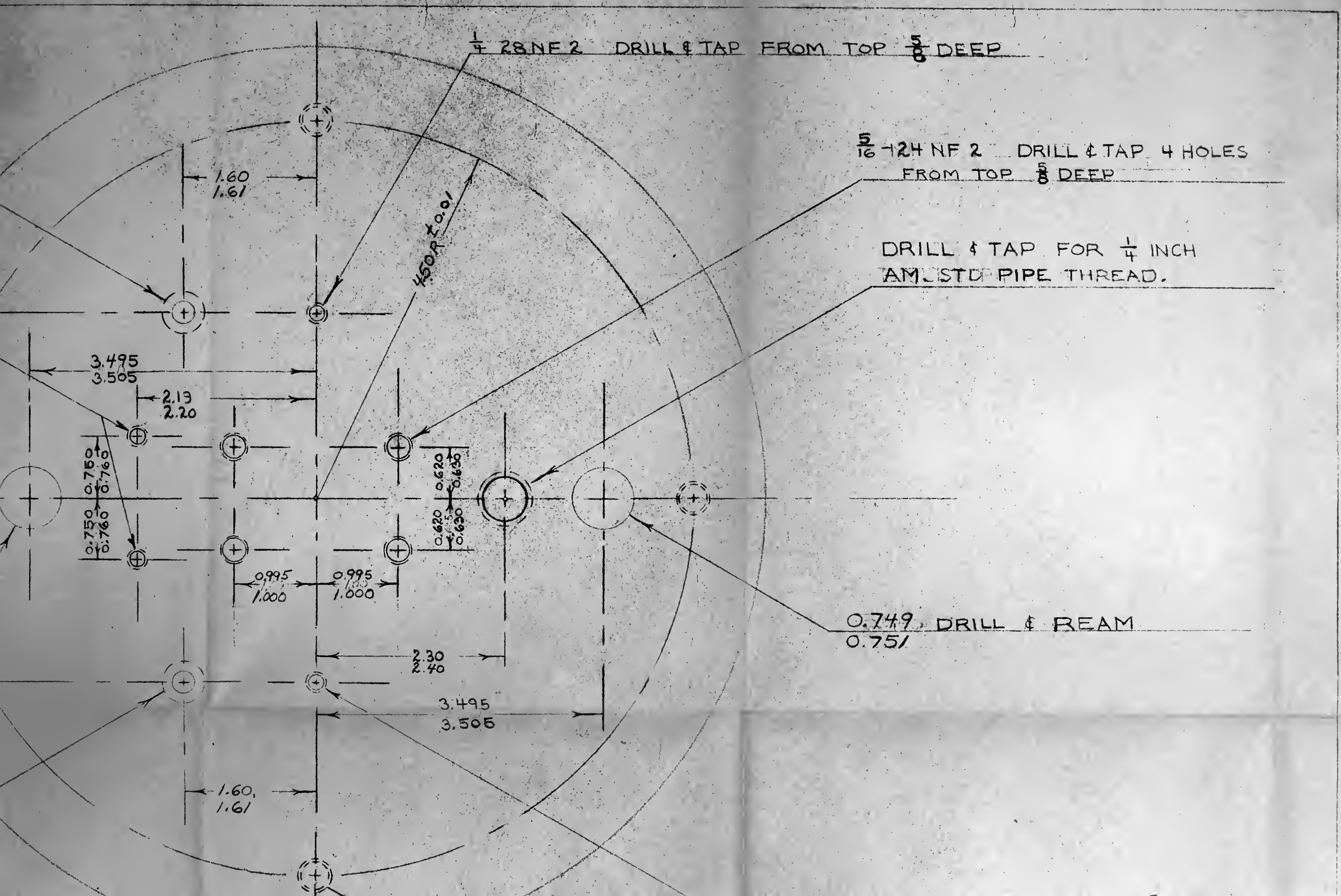
S. W. BACON



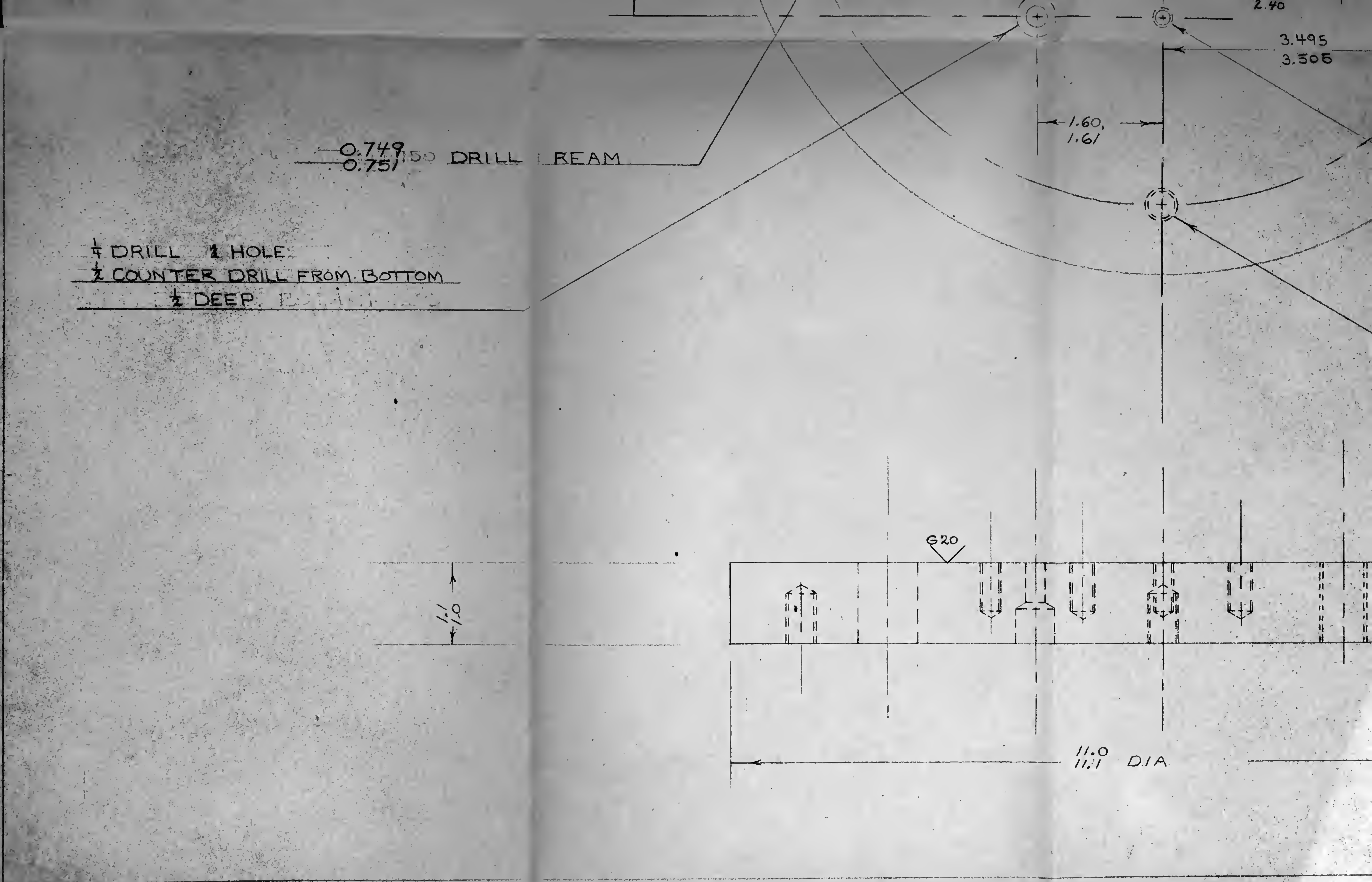
0.120 DRILL
0.1R
0.20 +0.02 -0.00
1.0



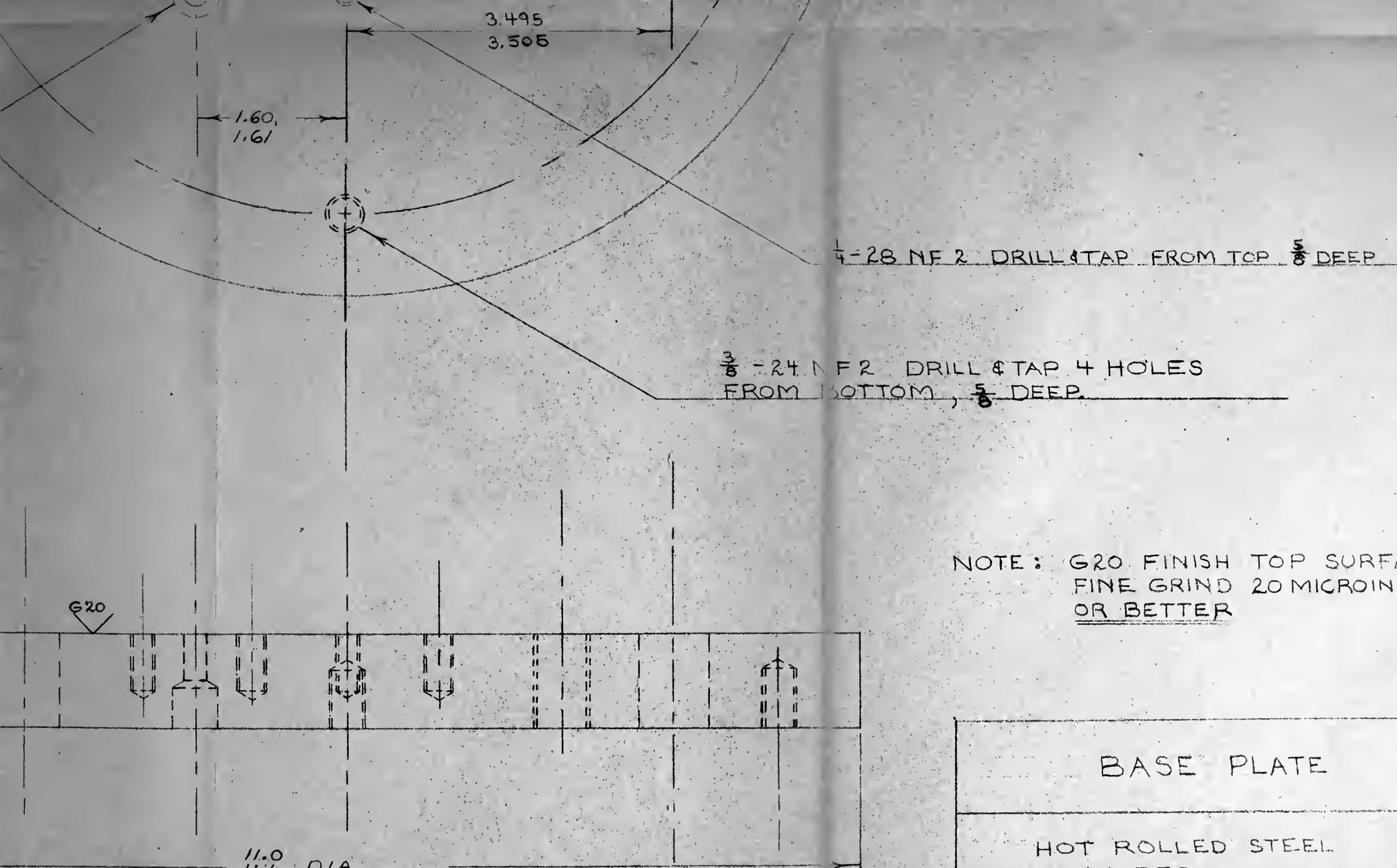
1/4 DRILL, 1/2 COUNTER DRILL FROM BOTTOM, 1/2 DEEP
1/4-28 NF 2 DRILL & TAP 2 HOLES FROM TOP 5/8 DEEP
1.60 1.61
4.50 R ± 0.01
3.495 3.505
2.19 2.20
2.25 2.26
2.25 2.26
0.750 0.760
0.750 0.760
0.620 0.630
0.620 0.630
0.995 1.000
0.995 1.000
2.30 2.40
3.495 3.505
1.60 1.61
0.749 0.751 DRILL REAM



1/4 28NF 2 DRILL & TAP FROM TOP 5/8 DEEP
5/16-24 NF 2 DRILL & TAP 4 HOLES FROM TOP 5/8 DEEP
DRILL & TAP FOR 1/4 INCH AM. STD. PIPE THREAD.
0.749 / 0.751 DRILL & REAM
450R ± 0.01
1.60 / 1.61
3.495 / 3.505
2.19 / 2.20
0.750 / 0.760
0.620 / 0.630
0.995 / 1.000
2.30 / 2.40

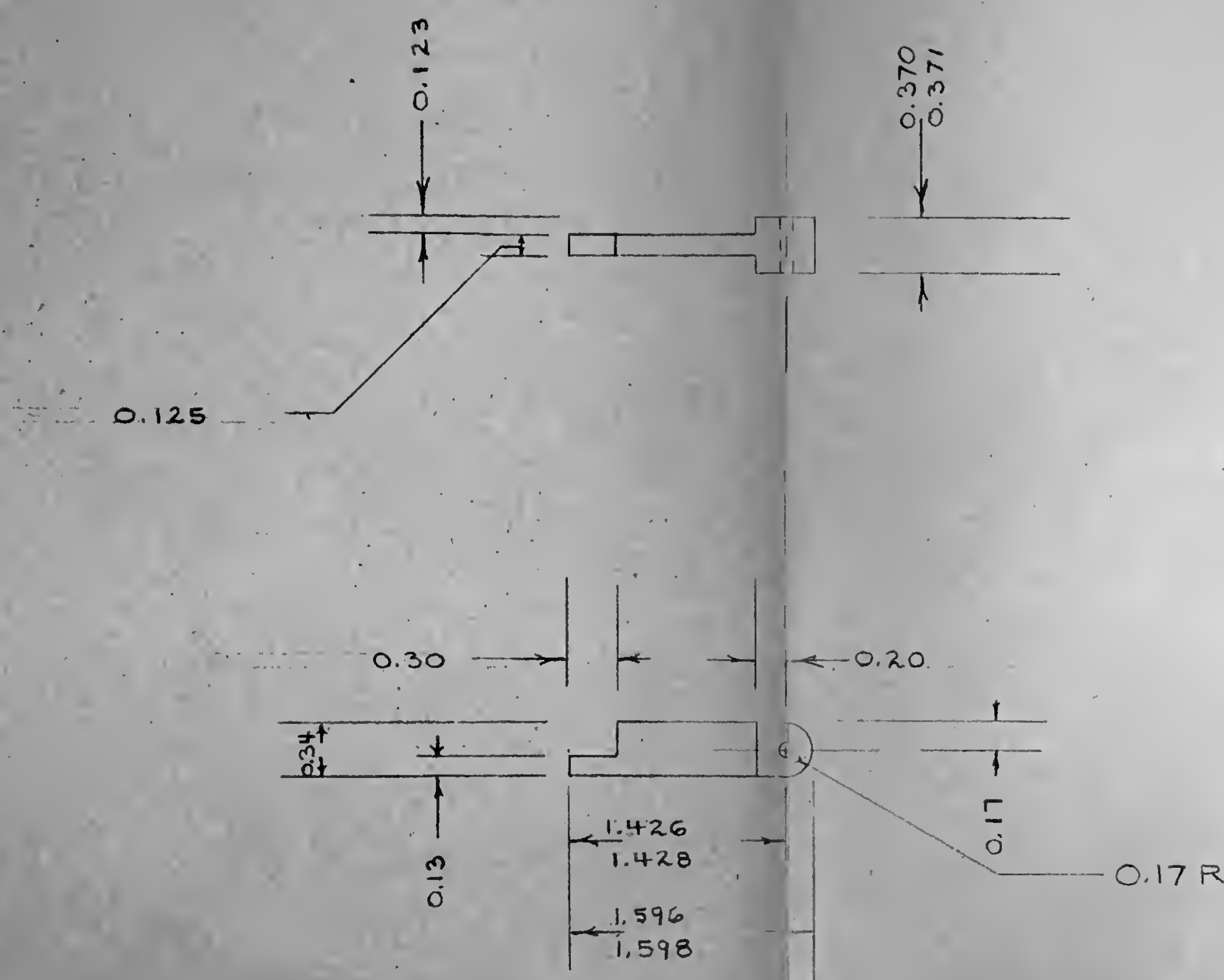


2.40
3.495
3.505
1.60
1.61
0.749
0.751
DRILL REAM
1/4 DRILL 1 HOLE
1/2 COUNTER DRILL FROM BOTTOM
1/2 DEEP
G20
1.1
1.0
11.0
11.1 DIA



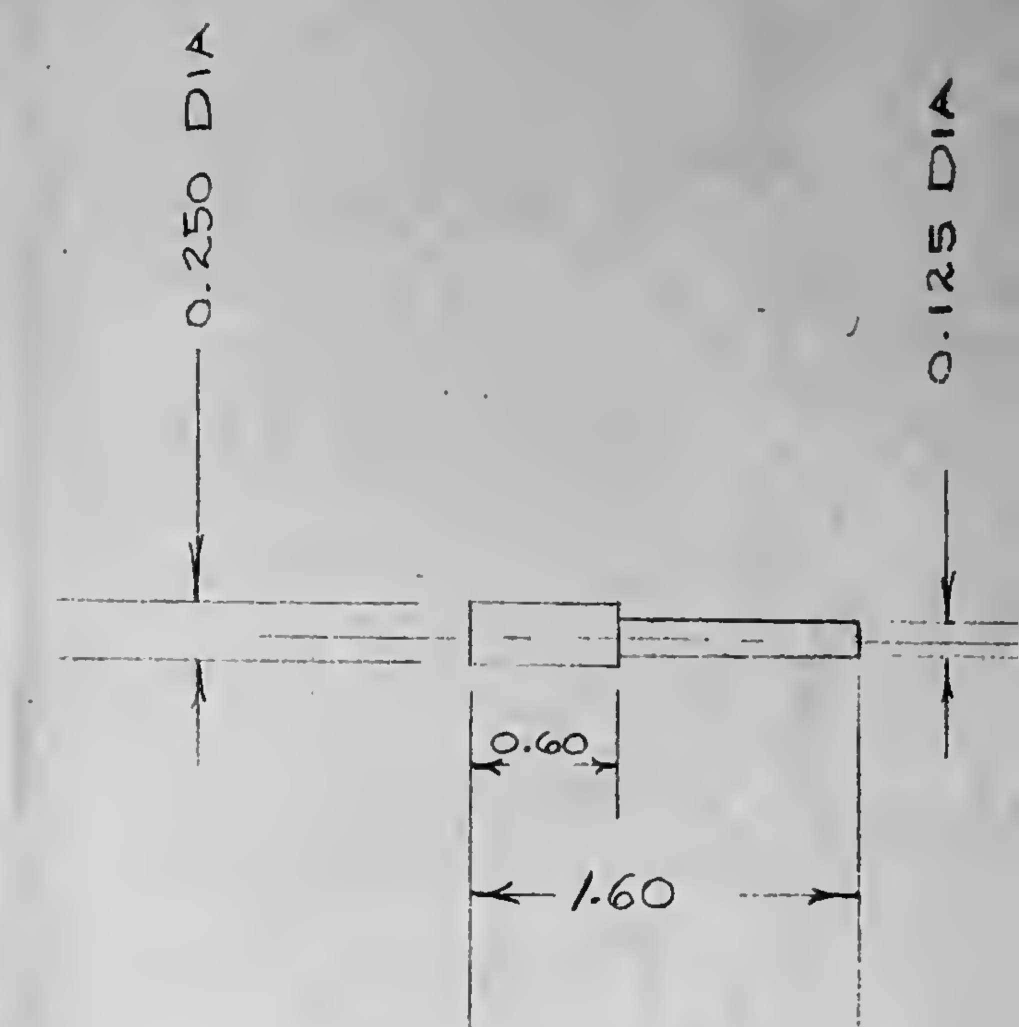
NOTE: G20 FINISH TOP SURFACE - FINE GRIND 20 MICROINCH OR BETTER

BASE PLATE
HOT ROLLED STEEL 1 REQD
S.W. BACON



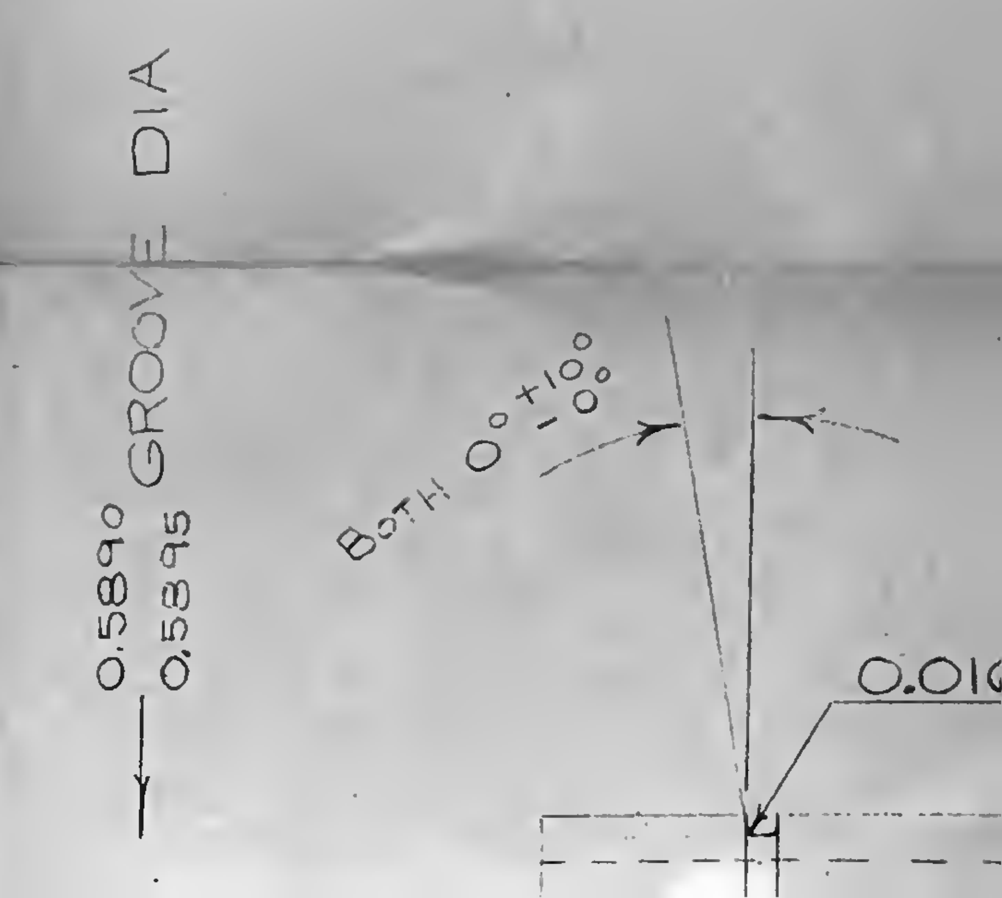
RELEASE LATCH

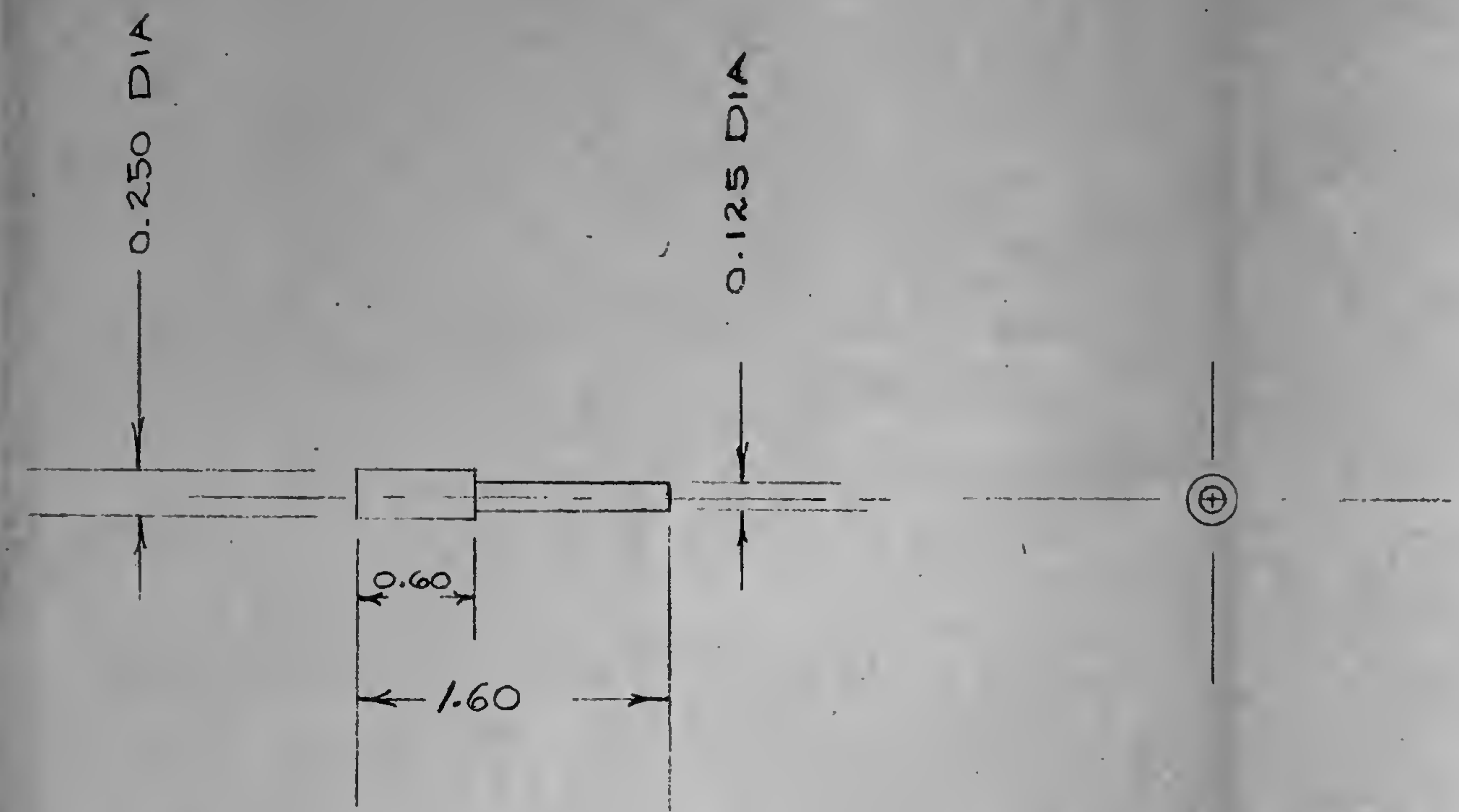
I REQUIRED - MATL, HOT ROLLED



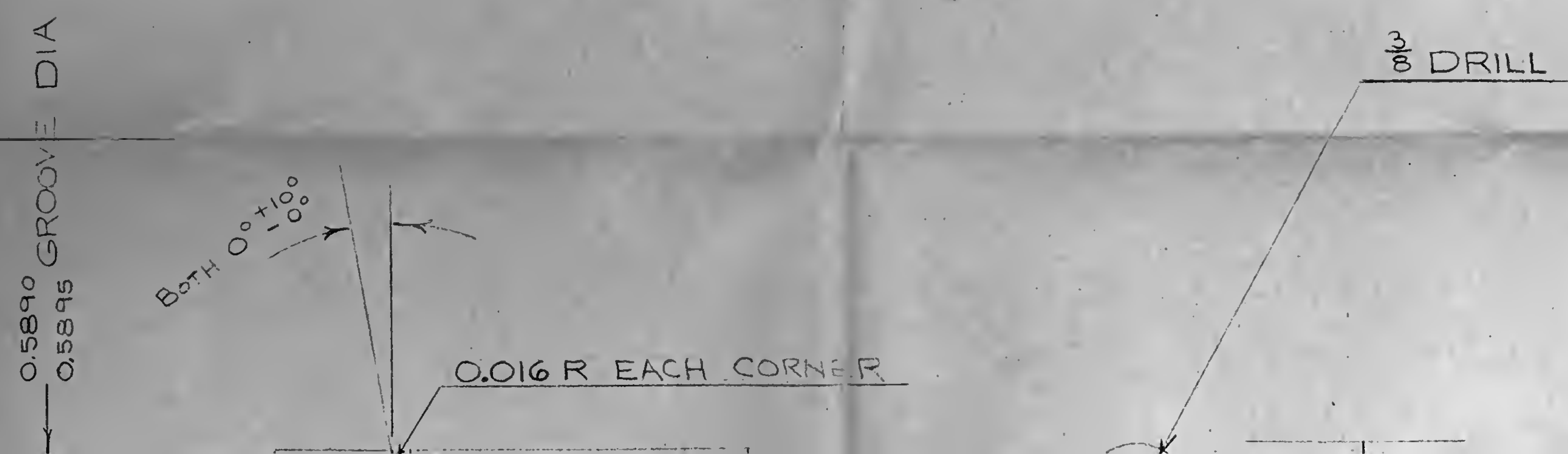
PLUNGER LOC

I REQUIRED, MATL. H



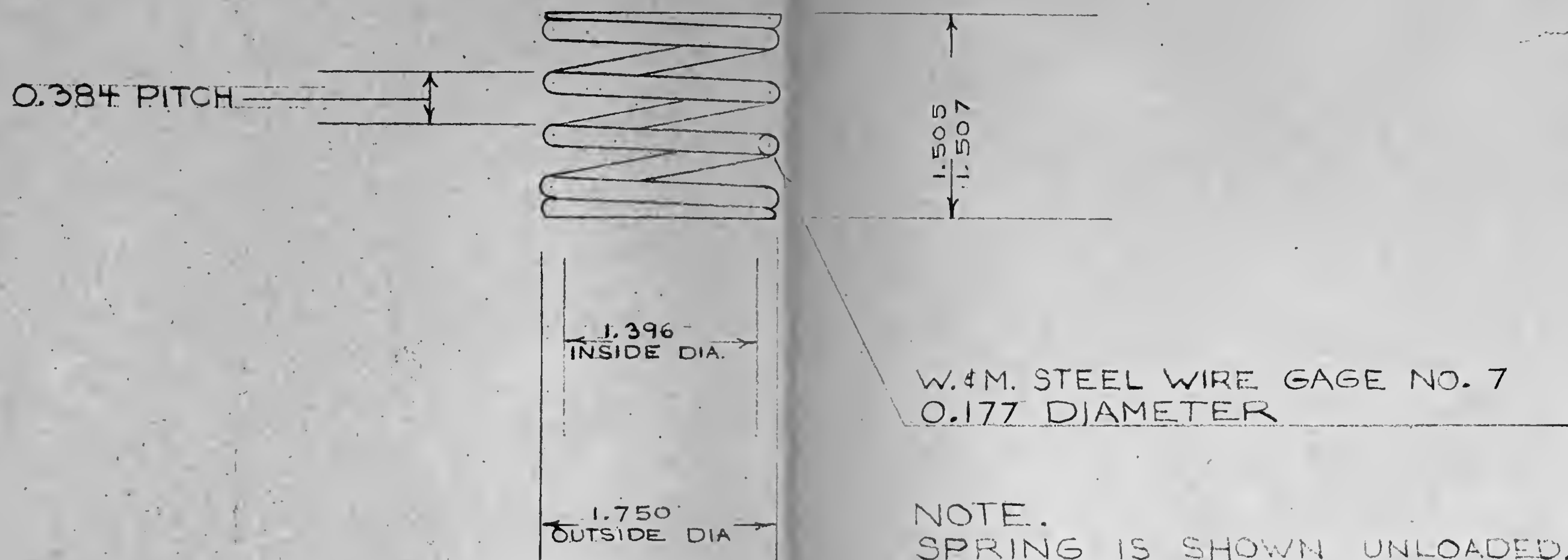


PLUNGER LOCK DELETE
1 REQUIRED, MATL. HOT ROLLED



RELEASE LATCH

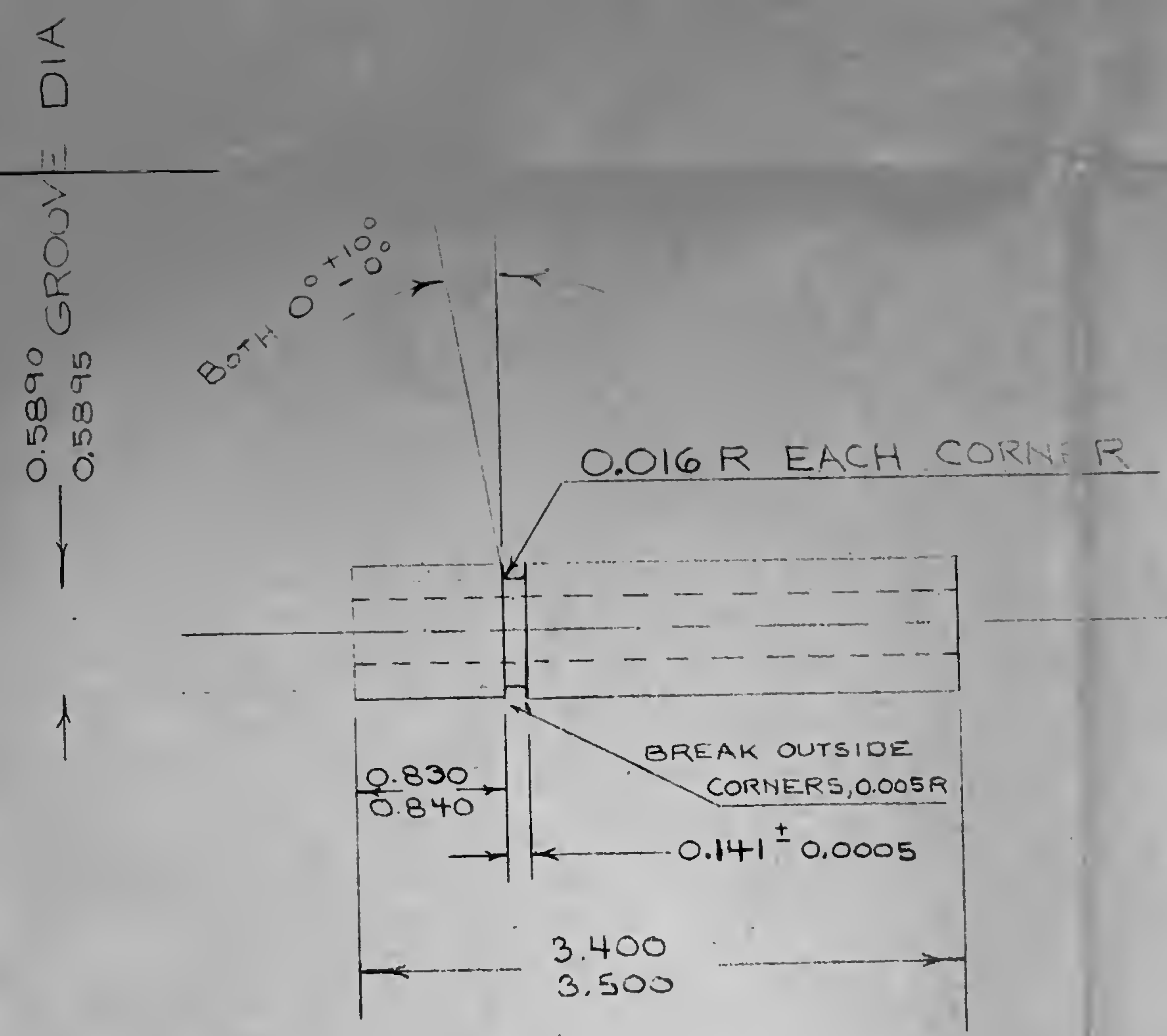
1 REQUIRED - MATL, H T ROLLED

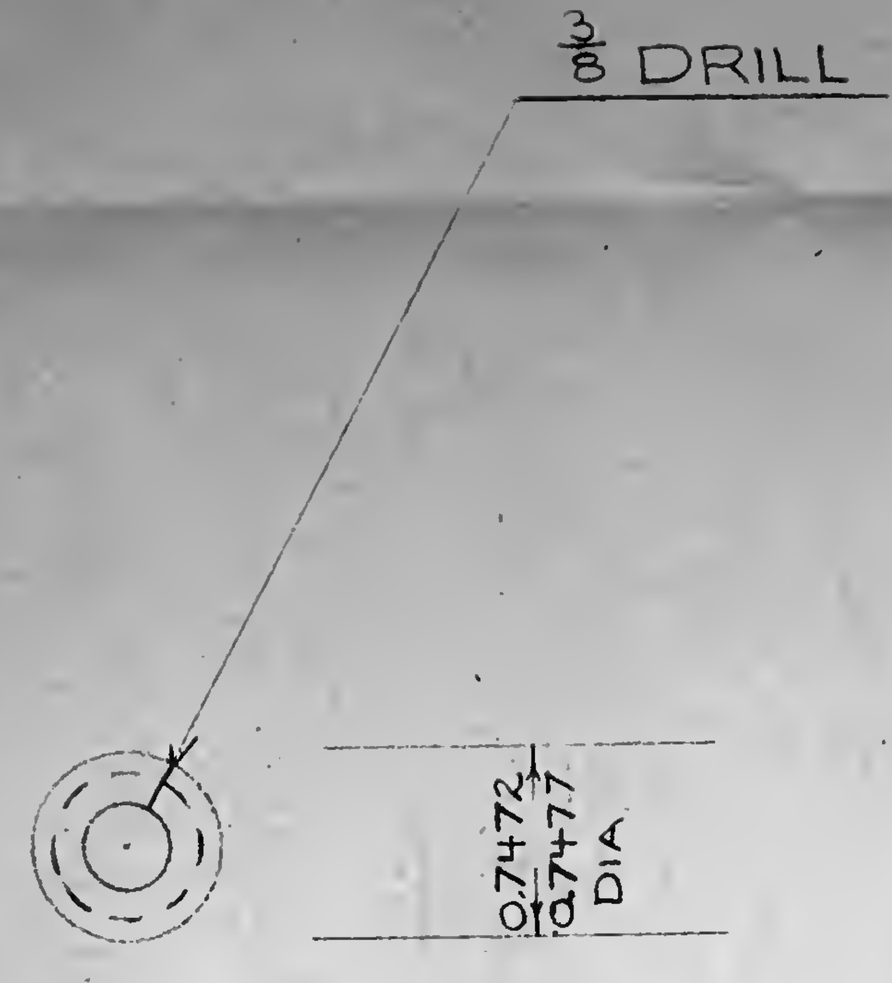


NOTE.
SPRING IS SHOWN UNLOADED.
CLOSED END COILS SQUARED & GROUND.
3 ACTIVE COILS, 2± CLOSED COILS.

RELEASE SPRINGS

2 REQUIRED MATL, S RING STEEL





NOTE
SURFACES & CORNERS OF GROOVE TO HAVE NO TOOL MARKS OR SCRATCHES & GROOVE FINISH SHOULD BE 15 MICROINCH.

GE NO. 7

WATER JACKET NIPPLES
2 REQD. MATL. HOT ROLLED STEEL.

UNLOADED.
SQUARED & GROUND.
LOSED COILS.

RELEASE MECHANISM DETAILS
NUMBER REQD. & MAT'L.- SEE DETAIL
S.W. BACON